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AN INVESTIGATION INTO A METHODOLOGY
TO INCORPORATE SKILL LEVEL EFFECTS
INTO THE LOGISTICS COMPOSITE MODEL

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The Logistics Composite Model (LCOM), a major part of the USAF maintenance manpower determination process, should be capable of providing information on the relationship between the workcenter's performance and skill level effects. This thesis investigates a methodology for incorporation into LCOM, which captures this relationship and measures the effects which skill mixture has on the workcenter's performance. A Q-GERT structural model of the workcenter was developed as a guide for understanding the skill level effects which are needed in this LCOM methodology. The developed LCOM methodology took each of the tasks' mean task times associated with each skill level and training situation, and weighted the task time with the respective probability of that task situation occurring. Specific areas of investigation involved a regression predictor model to quantify 3-level task times, a quantification procedure for determining the on-the-job training workload and the probability of a training situation, and determination of the probability that a task will be performed by a 3-level or 5-level technician, using information from the Comprehensive Data Analysis Program which provided job descriptions for each skill group. The simulation results showed that skill mixture effects have a distinguishable impact on the workcenter's performance.

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AN INVESTIGATION INTO A METHODOLOGY TO INCORPORATE SKILL LEVEL EFFECTS INTO THE LOGISTICS COMPOSITE MODEL

A Thesis

Presented to the Faculty of the School of Systems and Logistics

of the Air Force Institute of Technology

Air University

In Partial Fulfillment of the Requirements for the

Degree of Master of Science in Logistics Management

By

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This thesis, written by

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has been accepted by the undersigned on behalf of the faculty of the School of Systems and Logistics in partial fulfillment of the requirements for the degree of

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TABLE OF CONTENTS

Chapter		Page

LIST OF TABLES

Table Page

LIST OF FIGURES

Figure | Page

Chapter 1

OVERVIEW

The importance of maintenance manpower requirements determination cannot be overemphasized. The primary objective of this determination process is to search for the best mix of personnel in the various maintenance Air Force Specialty Codes (AFSCs) in order to maintain a desired capability in a given work environment. This objective is strongly affected by the cost of manpower. Presently, the Air Force is using the Logistics Composite Model (LCOM) for determining manpower requirements to meet this objective. LCOM is a large scale computer simulation model that simulates all phases of aircraft operations and main supporting functions at base level (10:1-3). Through systematic change in the manpower structure represented in LCOM, one can observe how these changes impact the overall performance of the complex maintenance system. In this way, LCOM aids the manpower analyst in making decisions on how to structure the work force for a given maintenance system and environment (17:1).

In recent years, not only are optimum mixes of personnel in different AFSCs important, but also the proper mix of skilled personnel within each AFSC (7:1-10). Without the proper proportion of skilled technicians to unskilled technicians, serious problems can arise in the area of work

productivity, on-the-job training and overall maintenance capability. As General Lew Allen, Air Force Chief of Staff, stated,

> . . . at the very time when we must significantly upgrade our defense capabilities, we are confronted with another serious blow, the decision by increasing numbers of our people to leave military service [14:22].

The retention problem has had its largest impact on the experience level of the work force. In the maintenance enlisted career fields, the loss of middle-grade noncommissioned officers (NCOs) is significant when one considers that the important functions of training and supervision are primarily their responsibility (14:20-25). Furthermore, these middle grade NCOs possess the skill knowledge which is necessary to sustain high maintenance capability levels. Secretary of Defense Harold Brown has stressed that the quality of our work force in terms of how skilled and experienced its members are has a direct impact on the readiness and capability of our forces, both home and abroad (14:25). The fact is, our work force is becoming more concentrated in the lower skill levels. This is having an adverse effect on our capability (14:23).

Because of the Air Force retention problem today, the available manpower resources must be utilized more efficiently than ever before (9:5-9). This places an additional constraint on the manpower requirements determination process to search for the best skill level mix within a workcenter. This mixture should maintain high maintenance capability

standards and ensure adequate training supervision, and learning progression for the lower skilled members of the work force (1:6). For example, a workcenter, which requires highly skilled workers, is manned with many lower skilled workers and not enough higher skilled workers. The workcenter will probably perform below standards because the insufficient number of skilled workers will be unable to keep up with the workload. Furthermore, the unskilled workers will not obtain the necessary instruction from the skilled workers to become productive members of the workcenter. The converse of this situation is also possible, where excess skilled workers are assigned to the workcenter and are idle a good part of the time. These hypothetical situations stress the problem which manpower managers face: in order to search for the bext mix of skill level manning requirements within a workcenter, one must understand the relationship between the workcenter's productivity and the skill composition of its work force. To date very little is known about this relationship (8).

Problem Statement

At the present time, the Logistics Composite Model does not distinguish the effects on a maintenance workcenter's productivity due to changes in the skill mixture composition of the workcenter's work force. In order for LCOM to be an effective tool in determining the best skill level mixture in the workcenter for handling a given

workload situation, a methodology must be incorporated into LCOM which will distinguish skill level effects. How this methodology can be developed and incorporated into LCOM and what affects it shows on the workcenter's performance are the primary problem areas addressed in this thesis.

Justification

Answers to the above problem statement will provide a general understanding of the dynamic relationship between the workcenter's productivity and the skill mixture of its work force. Furthermore, this study will provide an investigation into the ability of LCOM to predict the workcenter's productivity given a skill level mixture. With this prediction capability, a better skill level mixture can be obtained in the manpower requirements determination process.

Background

In order to proceed further into the investigation of the effects of different skill level mixtures on an aircraft maintenance workcenter's productivity, one must have a better understanding of what productivity is, and how an individual's skill level can affect productivity. (Skill level is a skill knowledge and ability level which limits the individual to specific tasks with the same scope.) Simply put, productivity is a ratio of output to input of an organization's production process. The larger this ratio is, the greater the organization's productivity will be.

How can one describe these outputs and inputs? According to Glaser, "the real meaning of productivity is to produce more . . . with the same amount of human effort [6:26]." This perspective stresses that productivity concentrates on the worker's efforts as the inputs and the product of this effort as the output. When looking at productivity in this way, the human effort is often quantified as the time it takes the individual to produce a unit of output. French and Steele, in their thesis (1979), "Productivity: A Function of Skill," state that productivity is not only a ratio of quantity to time but also, the output should possess a certain degree of quality. Quality, in that study, is the degree of conformance to design specifications or task procedure instructions that produce a unit of output which performs as specified (4:40) One should not view attempts to increase productivity as only finding new procedures, tools, and equipment to increase man's capability to produce more per unit of time. One must also take into account a worker's performance within the production system to produce a quality output in a timely manner.

How do these concepts of productivity tie into a definition of productivity for an aircraft maintenance workcenter? The main tasks of a workcenter include troubleshooting, removing and replacing components, inspecting aircraft systems, verifying a system works, repairing on-aircraft malfunctions, and working to facilitate other maintenance.

The output from the workcenter is the accomplishment of one of these main tasks. The time it takes the technician to complete these tasks will determine how many tasks the workcenter can complete. Also, the quality with which a worker completes the tasks will affect how many discrepancies the workcenter will have to accomplish in the future. A poorly accomplished task increases the probability that the maintenance task will be repeated again soon.

The human performance implications on productivity are evident in this maintenance context. Just what causes an individual's performance to vary? One model of behavioral influences on performance shows that an individual's motives and abilities are the two primary determinants of performance. The learning process which modifies and matures the person's motivation and abilities over time is based on feedback from past experiences (16:46). Motivational behavior, although important, is a highly qualitative factor which, depending on the individual and the work environment, has a wide variation of effects on individual performance. In order to deal with individual motivation, one must devise a scheme of what drives individual motivation and then evaluate the individual's motivational status constantly. This is beyond the scope of this study and the Logistics Composite Model.

For this research, the interest is in developing a general representation of the work force which can be divided into groups of technicians with the same average ability

level and not in a fractionalized work force of individually motivated workers. For this reason, the effects of motivation will not be included in this research and only the ability portion of the individual's behavior will be studied.

Historically, individuals have been classed according to their abilities: apprentice, journeyman, and craftsman. Likewise, the Air Force has an ability classification system for its personnel. It is a skill level designation of 1, 3, 5, 7, and 9 level where 1 is an entry level (completely unskilled in the abilities required for his job), 3 is an apprentice, and so on up to 9 which is a supervisor. These skill level designators signify that a person has the necessary abilities to successfully complete certain maintenance tasks. A 3-level is a person with elementary abilities within his specialty area. In principal then, the higher the skill level a person has, the more complex and diversified are his abilities. In this regard, the ability of the maintenance technician will determine to a great extent how he performs the maintenance tasks. If the technician's abilities are lacking, it will take the individual longer to do the task, and/or the individual will create more errors in performing the task thus reducing the quality of the final output. Inherent in the Air Force, skill level structure is a distinction in abilities between a 3-level and 5-level; a 5-level has more abilities than a 3-level.

A group which is composed of a certain mixture of 3 and 5-levels will have a group productivity level based upon that mixture of abilities. For this reason, a group with a certain mixture of 3 and 5-levels will possess a different group productivity level than one with another skill level mixture (motivation factors disregarded).

Together with the individual performance differences, dictated by the skill levels of the group members, the group's requirement to provide resources necessary to train the lower skilled individuals will also have an impact on the productivity of the group. The effectiveness of the training effort depends upon the emphasis which management places on training versus maintenance. A greater amount of time spent training reduces the amount of time available for maintenance. The choice between emphasizing training or maintenance determines how effective the training program will be in helping a 3-level progress to a 5-level (a more productive group member). Quite often, training emphasis is inversely related to the size of the workload (5:1-5).

In summary, the productivity of a maintenance workcenter, with a particular skill level mix, will be determined by three factors: (1) how long it takes various individuals in that workcenter to complete various tasks; (2) the quality of completed tasks; and (3) the training progress of the workcenter.

Literature Review

There have been two studies which specifically investigated the problem of how productivity is affected by different mixtures of skill level. French and Steel, in their thesis (1979), "Productivity: A Function of Skill," attempted to determine the productivity potential of each skill level for aircraft maintenance personnel at the base level (5:16). Their productivity premise was that a person's productivity

> . . . is measured in terms of three things: (1) the different kinds of tasks a person can do; (2) the time it takes to complete each kind of task; and (3) the quality with which the tasks are accomplished [4:20].

The types of data required by this productivity premise normally are not collected into the existing maintenance information systems. Thus French and Steele had to resort to Maintenance Data Collection (MDC) information on maintenance man-hours expended and number of maintenance actions completed as their primary productivity indicators. This information was not reported by skill level; therefore, extensive correlation and regression analysis had to be performed to isolate skill level contributions by 3 and 5-levels. Unfortunately, the lack of reliability inherent in MDC data tends to overshadow the accuracy of results obtained from this type of methodology.

Howell, in his Doctoral Dissertation (1980), "Manpower Forecasts and Planned Maintenance Personnel Skill Level Changes," primarily looked at the effect of different

task times for 3-levels and 5-levels on group productivity. Although he did not take into consideration training or quality factors, his study did develop the use of a Task Time Multiplier (TMULT) factor for determining the average percent of task time increase when maintenance is performed by a 3-level versus a 5-level (7:52). The technique consisted of averaging the relative increase in task time for each workcenter and then weighting each task by the relative number of times the task occurs using an LCOM simulation. The average, weighted, task time increase factor for each workcenter is then used to compute an overall TMULT factor which, when applied to an LCOM simulation consisting of all 5-level task times, would result in the same results as one using all 3-level task times. At the heart of Howell's research methodology was the use of the TMULT factor in 5-level/3-level mixture analysis. Using *a priori* probabilities based on the percentage of the skill level proportion of the work force, and assuming that all task crew sizes were two men and that a team consisting of a 5-level and a 3-level would perform the same as two 5-levels, the average performance level of any given skill mixture could be determined. Hence, given the proportion of 5-levels and 3-levels, the binomial expansion probability for that particular skill ratio would predict the average percentage of tasks performed at the 3-level task time (two 3-level persons performing the task) and the percentage of tasks performed at

the 5-level task time (two 5-levels or one 5-level and one 3-level together performing the task). Finally, multiplying the percentage of tasks performed at the 3-level task time by the system TMULT factor and adding the percentage of tasks performed at the 5-level task time would give a new estimated TMULT factor for the maximum expected accomplishment of the particular skill mixture (7:86). Howell also addressed various management policies for maintenance crew personnel assignment, and stated that such policies would impact the estimated TMULT factor of a given skill mixture. However, the assumption that direct binomial expansion probabilities can predict the percentage of tasks performed at the 5-level or 3-level task time does not effectively capture a realistic representation of actual workcenter performance. Such probabilities reflect situations which occur in a random fashion. This randomness is not representative of the technician to workorder assignment process which occurs in the workcenter. There exists a conscious effort by the workcenter supervisor to make these assignments according to a semistructured decision process to find the appropriate technician for the task. The resultant percentage of work performed by the 3-level and 5-level technicians under such a decision process then follows a unique pattern and not one which is random. Therefore, further investigation is still needed to capture the affect of skill mixture on maintenance productivity.

One particular research study which does reflect a realistic view of the maintenance activities performed by the different skill level technicians can be found in the Comprehensive Data Analysis Program (CODAP) performed by the United States Air Force Occupational Research Project. The accuracy and validity of CODAP Job Analysis data has been verified from the analysis of over 200,000 cases in approximately 150 occupational areas (11:6). CODAP Job Analysis data provides a variety of information including differences in work being performed by different skill level groups with respect to the percent of group members performing each task, the average percent of work time spent on the task by those who perform it, and the percent of group time spent on each task. One can clearly see applications for this type of data in the context of the skill level problem being investigated in this study. Using CODAP Job Analysis data will hopefully provide a means of capturing a realistic representation of work performance by 5-levels and 3-levels in a maintenance workcenter.

Research Objective

Using some of the concepts developed and verified by Howell and information from the Comprehensive Occupational Data Analysis Program, the objective for this research will be to develop and incorporate into LCOM a methodology by which one can capture the skill mixture relationships within

the workcenter and distinguish the effects which skill mixture has on the productivity and output of the maintenance workcenter.

Specific areas which will be looked at in this research include:

1. Development of a conceptual/structural model of the relationships between the maintenance tasks, the different skilled members of the work force, and the decision structure used to assign these tasks to the specifically skilled technicians in the work force.

2. Discussion into how the technician's maintenance errors can affect the workload and workflow of the workcenter.

3. Quantification of the relationship between 3-level and 5-level task times and "on the job training" task times.

4. Quantification of the "on the job training" workload within the workcenter by aircraft system and type of maintenance task in order to determine the probability that a task will be performed in an OJT situation.

5. Determine the probability that a specific maintenance task will be assigned and worked by a 5-level or a 3-level technician, using CODAP information.

6. Investigate the applicability of the above areas within the context of the Logistics Composite Model.

7. Incorporate those areas which are applicable into an LCOM methodology.

8. Application of this LCOM methodology to distinguish the affects which skill mixture has on the productivity and output of the maintenance workcenter.

Summary

This chapter clearly established the need to account for skill level affects within the LCOM manpower determination process. With th LCOM capability, the best skill

mixture for a work force in a given workload environment can be determined. This will enhance the maintenance manpower determination process. In order to achieve this capability, an appropriate LCOM methodology must be developed and incorporated within the existing LCOM software structure. How this can be done and what skill level effects are captured are the problem areas under investigation in this thesis.

This chapter further specified that the skill level effects to be isolated for this LCOM methodology will pertain to the technician's ability level while excluding other considerations such as individual motivational behavior. These ability levels affect the workcenter's productivity in three areas: task times, error rates, and on-the-job training load. All three of these skill level effects, when increased by increasing the proportion of 3-levels in the work force, will have an adverse affect on productivity because more time is required to accomplish the same workload.

The Literature Review on past research efforts led to the discussion of the LCOM methodology used by Howell in his dissertation. Howell tried to isolate the skill level effects of the task time factor by weight averaging the mean task times attributed to the different skill level groups. However, the *a priori* probabilities used to characterize the amount of work done by each skill group, and thus the weighting factors, were found to be inappropriate in capturing the

semistructured decision process used by the workcenter supervisor in assigning technicians to tasks. In order to characterize the work done by 3-level and 5-level technicians more accurately, the Comprehensive Occupational Data Analysis Program was presented as a possible solution.

With the skill level factors which affect productivity identified, and having established the need to capture the semistructured decision process used in the workcenter for task assignments and the proper workload proportion among the skill level groups, the main objective of this research to develop an LCOM methodology to determine the skill mixture affects on the workcenter's performance can be pursued. The remainder of this thesis will concentrate on the development of the structural concept of this methodology, the specific methodology to be incorporated into LCOM, and how this methodology can be used in a research design to isolate and measure the skill level effects on workcenter performance.

The structural model development and resulting discussions on the skill level affects on the relationships outlined in the structural model (specific objectives 1 and 2 listed earlier) will be presented in Chapter 2. Chapter 3 will discuss how this structural model can be developed into a specific LCOM methodology; how all the necessary quantification procedures for task times, 3-level and 5-level work probabilities, and on-the-job training load will be

developed; and finally what type of research design would be appropriate to isolate the skill mixture effects on work-center performance (specific objectives 3 through 8 listed earlier). The results and analysis of the LCOM methodology developed in this research and the research design will be discussed in Chapter 4. Chapter 5 will contain the conclusions and recommendations for further research.

Chapter 2

CONCEPTUALIZATION

In Chapter 1, differences between 3-level and 5-level maintenance technicians were explored with emphasis on the different ability levels of these two skill level groups. Also, the relationships of skill level with task times, error rates and training requirements were discussed. This chapter will develop a conceptual framework of the maintenance system which the maintenance workcenter operates in and a structural model of the workcenter's operations. The purpose behind this conceptualization process and structural model is to provide a formal framework of the objects and activities, and the relationships between these system components. This method of viewing the system facilitates the understanding and discussion of all the cause and effect relationships present in the maintenance workcenter system. In particular, the structural model will be developed in order to clearly show how the semistructured decision process for assigning technicians to tasks works, and how specifically the skill factors of task times, error rates and training committments affect the relationships shown in the structural model.

Once the understanding of the system has been formalized in the structural model, the knowledge developed will

provide the guidelines on which to build the LCOM methodology. If the LCOM methodology can be built to meet all the guidelines set from the structural model, then the methodology will effectively capture the relationships expressed in the structural model. Also, if the structural model accurately represents the actual workcenter system found on the flightline, then the methodology will possess the same accuracy and validity of the structural model.

Before actually presenting the structural model of the workcenter, a general discussion of the overall maintenance system and goals will be presented. Out of this overall maintenance system to specific workcenter conceptualization process, the individual workcenter's objectives will be defined and how the individual workcenter and its objectives fit into the maintenance system will be developed. The conceptualization process will also provide an understanding of how the overall maintenance system affects and influences the individual workcenter in the development of its decision process for making workorder assignments to specifically skilled technicians. Understanding these conceptualized relationships in the maintenance system will aid in representing the decision process in the structural model of the workcenter. Finally, the whole process of conceptualization and structural model development will provide some insight into what input measurements will be

required for the LCOM methodology and how to evaluate the workcenter's performance and capability.

Conceptualization of the Maintenance System

A macro view of the overall maintenance system can be represented by a black box interacting with the environment. A black box is a way of representing a very complex system in which one is only interested in its reaction with other systems in its environment and not how those reactions are developed and processed within its complex system. In the environment are many systems which affect maintenance such as the aircraft design and procurement system, weather factors, the supply, budget, and personnel systems, maintenance directives from higher authorities, and the operations system (see Figure 2-1). The supply, budget, and personnel systems are the prime determinants of the quantity and quality of resources used by the maintenance system. The aircraft design and procurement system provides the primary objects of the maintenance system, the aircraft. These aircraft have certain design characteristics, built into them by this environmental system, which define the type of maintenance requirements, and a set break rate pattern. The maintenance directives from higher authorities identify to a great extent, prescribed maintenance management techniques and scheduled maintenance requirements to be performed by the maintenance system. The weather factors are set and

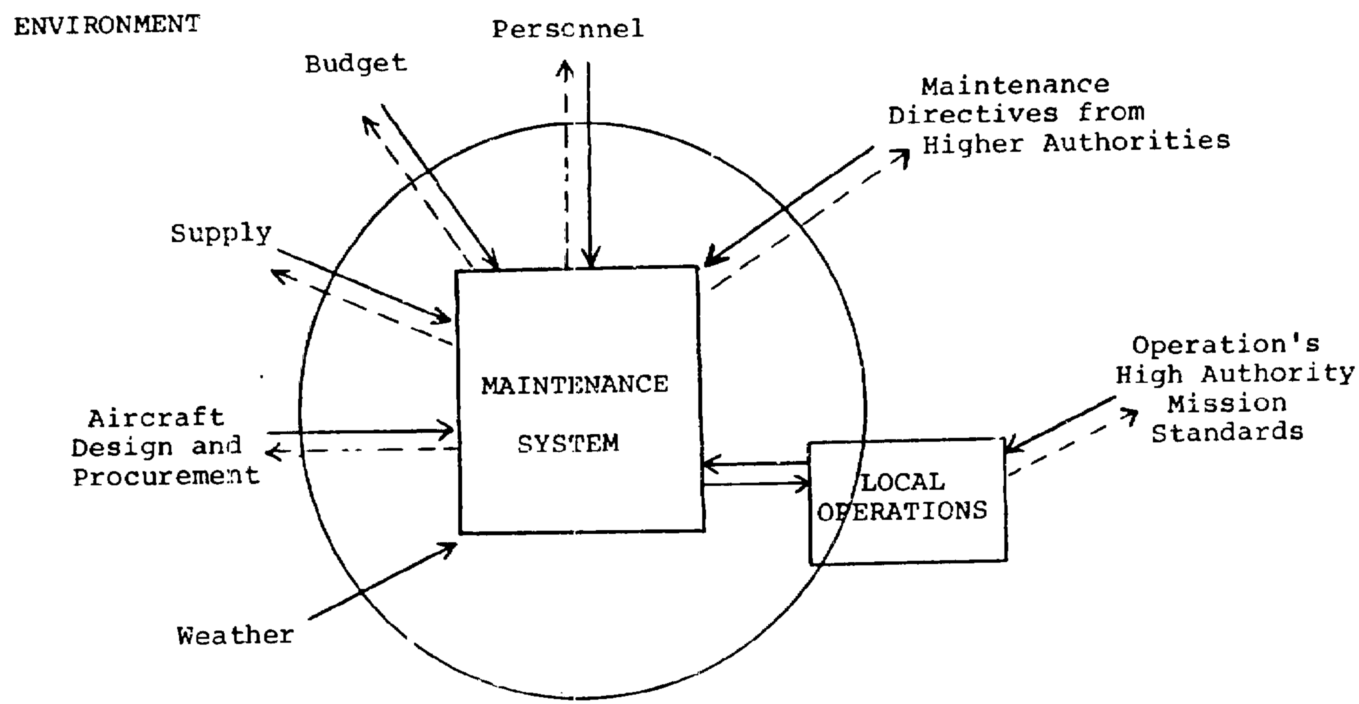

Fig. 2-1. MACRO View of the Maintenance System As A Black Box Reacting With the Environment

uncontrollable, and are constraints which the maintenance system must consider in its planning activities. Finally, the operations system is the prime driver of the maintenance system's mission. The operations system is the source of demand for the maintenance system's output. This demand is based upon mission requirements set by higher authorities in the Air Force system. These mission requirements are often constant and inflexible. The wing (or local) portion of this operations system translates these mission requirements into realistic training and mission sortie requirements. These translated requirements represent the direct demand placed on maintenance. The overall maintenance system goal, therefore, is to satisfactorily meet this direct demand by providing mission capable aircraft to operations.

All of these environmental systems affect the maintenance workload in some way; however, it is the aircraft design characteristics and operations' flying commitments which are the prime determinants of workload. The rest of the environmental systems affect workload by defining the capability with which the maintenance system can process this workload. These environmental systems limit maintenance capabilities by controlling the quantity, type, and quality of resources used by the maintenance system and the procedures with which they are used. The processes which maintenance goes through to influence these environmental systems to provide more or better resources are long term efforts.

They can be described as long range objectives for improving capabilities in the future, but do not affect the current operational processes used by the workcenter to meet the current primary objectives of meeting operations' sortie needs. For the short term then, how maintenance handles the operation system's direct demand within the existing confines of the maintenance system's resources, activities and aircraft, will determine how well maintenance meets its objectives. It is this short term process for handling the direct demand, which is of concern to us in developing the workcenter structural model.

Having established this general macro view of the maintenance system, it is now possible to investigate how the internal subsystems within the maintenance system interact to meet the primary objective. Of prime interest is how operations' demands are communicated from operations down to the workcenter and how the workcenter's individual objectives are formulated in support of the overall maintenance goal. Figure 2-2 shows the key subsystems and the interactions which occur to accomplish this goal transmission to individual subsystems.

The maintenance control subsystem is the primary contact point with operations. Much negotiation goes on between the people in this subsystem and the people in operations. The result is an assessment by the maintenance control subsystem as to the needs or demands of operations and

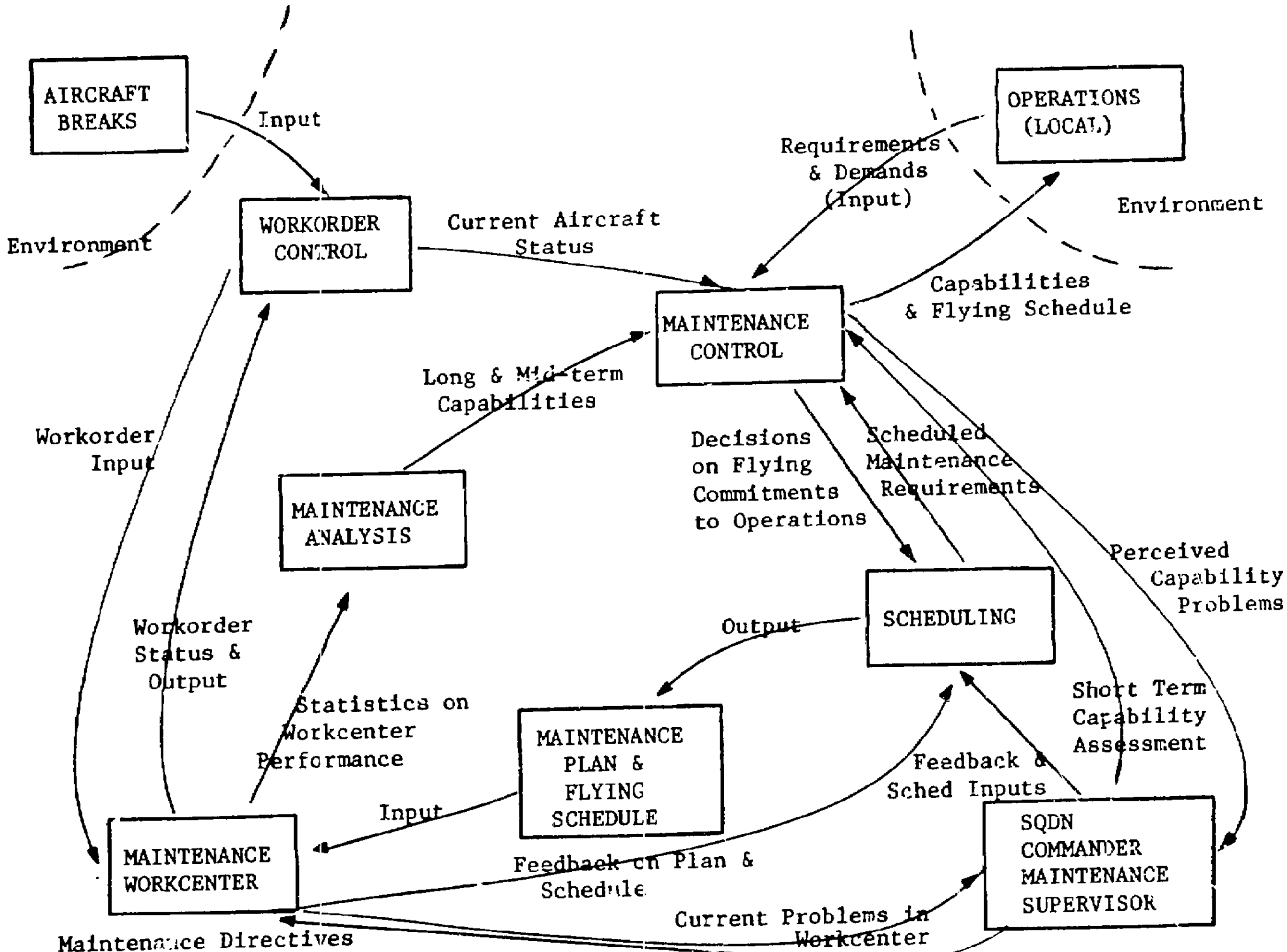

Fig. 2-2. Maintenance Subsystems and Their Interactions

feedback as to whether past demands have been met satisfactorily (an assessment of goal accomplishment). Further information about current aircraft status, workcenter near term and long term capabilities, and scheduled maintenance commitments, provides an assessment by maintenance control and scheduling on how to best accomplish the demand for sorties. This assessment is formulated into a maintenance plan and flying schedule. The maintenance plan sets forth all scheduled maintenance requirements and the flying schedule is developed to stay within the limitations which the aircraft break rate patterns, workcenter launch and recovery capabilities, and scheduled maintenance requirements determine. The objective of the maintenance plan is to meet the needs of operations yet stay within the capabilities of maintenance. Quite often, if the plan is not fulfilling this need, then maintenance capabilities are lacking in the time it takes to regenerate and keep the aircraft in good repair. Areas of weak capability are identified and attempts are made through local management actions to resolve the capability problems and speed up the maintenance processes at the workcenter level.

The maintenance plan and flying schedule are the primary guidelines by which the workcenter must organize its workload. In fact, the workcenter's operational goal is to fulfill the work requirements necessary to accomplish the maintenance plan. If there is a capability problem within

the workcenter, the operational goal dictates that actions are to be taken to speed up the maintenance process and alleviate the capability problem. In this manner, the maintenance plan and flying schedule can be achieved with greater success.

Structural Model Development

At this point, a discussion of the resources, objects, and activities which affect the maintenance workcenter system is needed to develop the structural model. The resources which the workcenter uses to accomplish its objective include manpower, equipment, facilities, and supply resources. As discussed earlier, these resources define a limited capability level and are primarily set by environmental factors but can be changed over time. Since this study concentrates on only the affects which the manpower resource has on the workcenter's objective, unlimited equipment, facilities, and supply support will be assumed. The objects, which act as the inputs to the workcenter's maintenance process, are the workorders. Each workorder is associated with a unique task and set of task attributes. These task attributes are especially important since they determine the technician assignment process. The workcenter's maintenance process involves taking the workorder inputs and completing them according to the guidelines and commitments set forth by the maintenance plan and flying schedule. The process involves three major activities: a workorder evaluation activity,

resource assignment activity, and a task activity. The following definitions are presented to clarify the understanding of the resources, objects, and activities just discussed:

Manpower resource - maintenance technicians with a prescribed ability level which segregates them into two groups, one group being the apprentice technicians (3-levels) and the other group being the skilled technicians (5-levels and above).

Equipment - tools, test equipment, power units, technical data, vehicles, and test stands.

Facilities - hangars, work shops, and ramps.

Supplies - spare parts such as nuts, bolts, small electrical components (resistors, amplifiers, transducers), black boxes, and any part which comes out of bench stock or which is ordered from supply.

Workorder - a job demand on the workcenter, the generation of which is predetermined by the flying commitments set forth in the flying schedule, the internal design break rate of the aircraft, and the requirements set forth in the maintenance plan.

Task attribute - involves the identification of a workorder to a specific aircraft system/component and the type of maintenance action which will be required to correct the task discrepancy, and specifies how many resources are required to be assigned to the workorder, what skill level requirements are needed as a minimum and what priority the work will have.

Workorder evaluation activity - involves a determination of the workorder's task definition attributes, prioritization of tasks within the current workcenter workload, and determination of the availability of the aircraft required to be worked by the workorder.

Resource assignment activity - assignment of all resources to a task according to its task attributes; these resource assignments must almost always be done concurrently or the workorder will be placed on hold.

Task activity - begins when all necessary resources have been assigned and the aircraft is available; the length of this activity is dependent on the task difficulty and

ability level of the technicians and whether the task is being used for training (task completion is defined as when the workorder has been resolved by the technician and cleared from the workcenter subsystem).

Workcenter supervisor - the individual who performs the workorder evaluation activity and resource assignment, and coordinates the workcenter's actions with other maintenance subsystems.

Training - over the shoulder, on the job instruction conducted during a task activity; training requirements are assessed by the workcenter supervisor in the resource assignment activity.

Backorder queue - the workorder waiting line prior to resource assignments in which workorders are prioritized.

This completes the definitions of the resources, objects, and activities in the workcenter system. A structural model which illustrates the relationships between these components, the skill level relationships discussed earlier, and their affects on the workcenter's objective will now be presented. The network modeling tool used to develop the structural model is known as the Queueing Graphical Evaluation and Review Technique (Q-GERT). Q-GERT is a modeling and analysis language based on a network scheme designed to represent and simulate the activities which occur in most work situations (15:1-2). Q-GERT was chosen for representing this workcenter structural model because the modeling concepts are representative of the maintenance activities and the network presentation will provide a precise symbolic view of these activities in which to communicate the complex structure of the workcenter. Appendix A contains a summary of the Q-GERT symbols used in this

chapter. For a more detailed discussion on Q-GERT network modeling, see Pritsker (1979).

The Q-GERT model of the workcenter begins with Figure 2-3 and concerns the workorder input to the work-center. When the workorder first arrives at the maintenance workcenter, the supervisor performs the workorder evaluation activity. If aircraft availability was limited due to multiple workcenters needing to work the same aircraft, the workorders would not leave this section of the Q-GERT model until the workorder could be matched with its particular aircraft. Thus, for purposes of this discussion, aircraft availability will be assumed to be unlimited in order to focus on the manpower effects in the structural model. The source nodes generate the workorder inputs and assign all of the task definition attributes (see transaction attributes 1 through 5, Table 2-1). Next, node 10 assigns a task increment number (comparable to a workorder number) to each workorder for easy identification through the workcenter network (transaction attribute 7, Table 2-1). Finally, the workorders are sorted and placed in a backorder queue according to their priority. Note that workorders which are balked back to this queue are also placed in the queue according to their priority.

Following the workorder evaluation activity, the workorder is transferred to the resource assignment activity. Since nonmanpower resources are assumed to be unlimited,

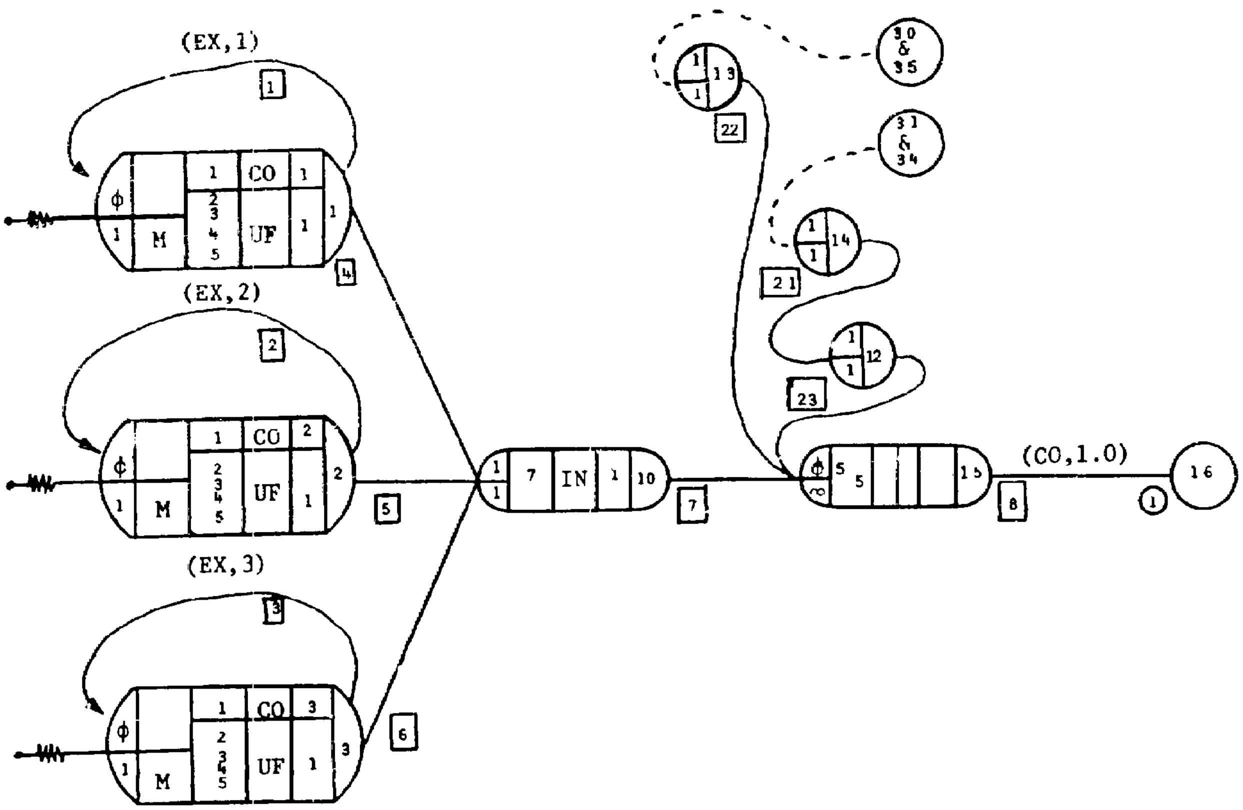

Fig. 2-3. Q-GERT Structural Model of the Workcenter's Workorder Evaluation Activity

TABLE 2-1

Q-GERT Transaction's Attribute Definitions

ATTRIBUTE	VALUE REPRESENTATION
A1	•Type of Aircraft System/ Component
A2	•Task Classification
A3	•Team Size •Time Which Assistant is Waiting for Assignment
A4	•Skill Requirement •Assistant Identifier (6)
A5	•Workorder Priority •Resource Assigned to Transaction
A6	•Task Time
A7	•Task Increment Identification Number

this activity boils down to a complex decision mechanism for assigning the maintenance technicians to the workorders. Figure 2-4 represents this decision mechanism used by the supervisor. The supervisor first takes the highest priority workorder in the backorder queue and notes the crew size required by the workorder and the minimum skill level requirements of its task. The Q-GERT model distinguishes these two items through a series of sort decisions in nodes 16, 17 and 18. Node 16 separates the one man and two man tasks. Node 17 and 18 separate the 5-level tasks from the 3-level tasks. Once this is done, the workorder is ready to be assigned to a maintenance technician. When assigning the workorder, the workcenter supervisor will take note of the technician's technical abilities. The supervisor will try to match the difficulty level of the task to a technician with comparable abilities (this is why the skill level requirements of the workorder are assessed). The basic objective behind matching abilities to the task difficulty is to minimize the average task times of all tasks through the workcenter. Through minimizing average task time, the workorder's time in the workcenter system will be decreased not only in the task activity section but also in the backorder queue where the workorders will wait less time for the manpower resource. Furthermore, smaller workorder system times will improve the mission capable rate of the aircraft (a function of how long workorders are open), and smaller

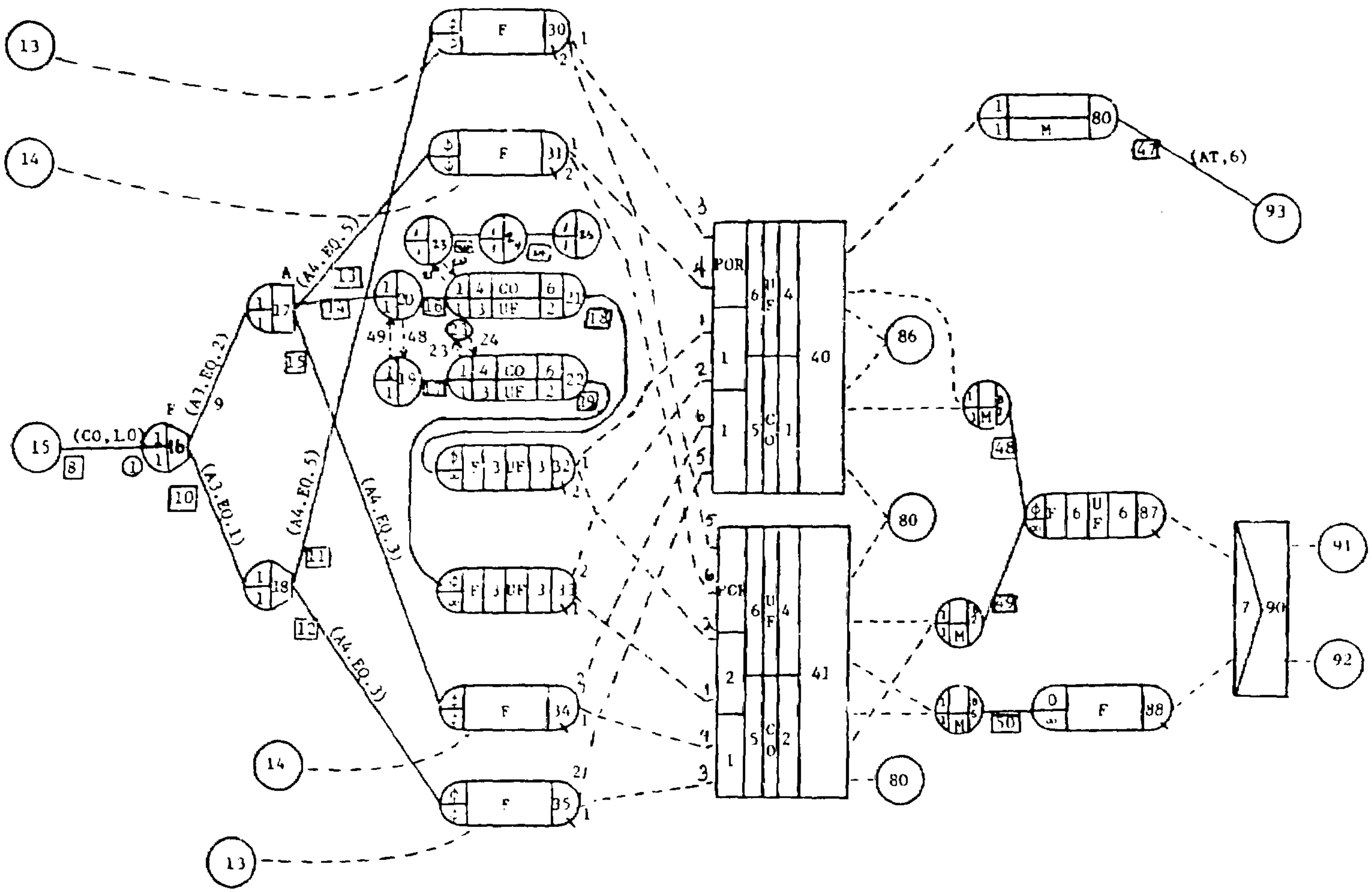

Fig. 2-4. Structural Model of the Workcenter's Resource Assignment Activity

task times will tie up the aircraft for less time and allow other workcenters to complete their workorders on the aircraft. If excessive delays were allowed to occur in one workcenter, other workcenters would not be able to meet their mission requirements and possibly cause the failure to achieve the overall maintenance goals.

The decision of which technician to assign to the workorder depends on how many technicians are available in the workforce and the ability level of these technicians. If technicians are available, the supervisor will make assignments according to the following rules:

1. Maximum assignment of 3-levels with 5-levels on two man tasks.

2. Three levels can perform tasks if they are capable (i.e., the type of task and its relative difficulty will dictate whether a 3-level can accomplish the task). A set number of tasks are predetermined to be easy enough for 3-levels and are represented as such in the task description.

3. Two 3-levels will be assigned a task if no one else is available. Likewise, one 3-level will be assigned to a one man task if no one else is available.

4. If a task requires two people but only one is available, the supervisor will dispatch the one and the next man to become available will be assigned to the task as an assistant. Task time will be adjusted to consider one man performing a two man task over certain time period before

his assistant arrives. One man working alone on a two man task will require a longer task time.

5. If a task with a particular skill requirement arrives but that skill resource is not available, the task will be assigned to whoever is available.

The mechanism used in the Q-GERT model to accomplish these rules is a series of queues associated with two resource allocate nodes (see Figure 2-4). One allocate node represents the 5-level technicians and the other represents the 3-level technicians. Each queue shows a preference of one resource over the other in order to assign the correct ability level to meet the task's minimum skill requirements. If that resource is not available, it will check to see if the other type resource is available. The workorder transaction is then routed to the appropriate queue based on its task attributes as discussed earlier. In the case of the two man tasks, a duplicate transaction is also routed to the assistant queue.

The task times which are assigned at the allocate nodes are based on the ability level (3-level or 5-level) of the resource actually assigned. However, for workorders requiring two man teams, the actual task time assignment is based on the primary team member's skill level. An assumption is made that the primary member will do the work and will accomplish the task in accordance with his abilities and not the assistant's. If a 3-level was assigned as the

primary team member, a nodal modification would occur to route the duplicate workorder transaction for the assistant to the assistant queue which gives priority of resource assignment to the 3-level resource. The task time of the assistant would be the same as the primary team member and both would be adjusted for any delays in assistant assignment. The two transactions would then be matched on the opposite side of the allocate nodes and passed on to the task activity section of the workcenter network.

If no technicians are available at the allocate nodes, the workorder transaction is balked back to the back-order queue for later resource assignment. If the workorder transaction involved a duplicate transaction for an assistant, a nodal modification will occur when the original transaction is balked and the duplicate transaction will be killed.

The task activity section of the Q-GERT model is presented in Figure 2-5. It begins by scheduling the task activity according to the transaction's task time attribute. At the expiration of the task time, the workorder transaction is completed, the resources are freed and the transaction leaves the system. This completes the basic workcenter network. However, the effects of technician errors and training requirements can also be considered for further embellishment of the structural model.

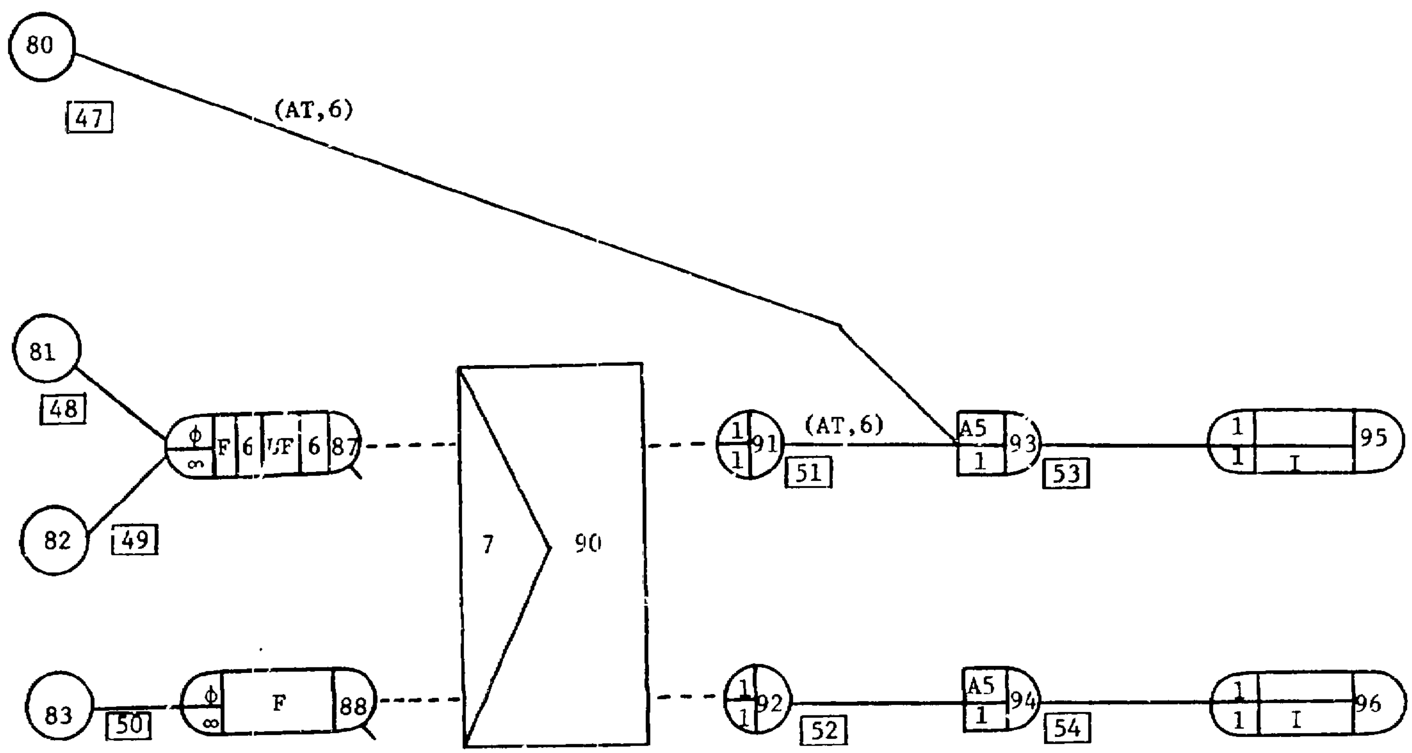

Fig. 2-5. Q-GERT Structural Model of the Workcenter's Task Activity

The impacts of technician errors due to mismatching skill level and task difficulty are twofold. First, the individual may complete the task but on completion discover that he did not resolve the problem. In such a case, the workorder will be reworked by the same technician or rerouted back to the backorder queue for reassignment to someone with a higher skill level. The second possibility is that the error will go undetected at the time of task completion and the workorder will leave the system. In this case, the failure rate for that system will be increased.

The impacts of training requirements on the structural model are more complicated. All of the 3-level resources must constantly be evaluated and updated on their training progression. When a workorder arrives at the workcenter, the supervisor determines if there is a three level who needs and is available for training, and if there is someone present who is qualified to train the 3-level. When both are available, the workcenter supervisor will assign the two individuals to the workorder if time constraints on the workorder permits the extra training time and if the workload in the workcenter does not require the trainee to work on another job for which he is already qualified. Once the training is complete, the supervisor will have to update the trainee's training status progression. Quite often though, it takes several training sessions on a particular task or aircraft system before the trainee

can be completely qualified on the task. In Chapter 3, we shall propose a method for determining the probability that a workorder will be utilized for training purposes. Given the training probability, a workorder, upon input to the model, will be identified as being a training task or not. If it is not a training task, the workorder task time assignment will be handled as discussed earlier. If it is a training task, the transaction will be processed as a two man task with a three level designated as the primary team member (this will cause the task time to be generated under the 3-level task time distribution). The training task will only be accomplished if a 3-level and a 5-level are available. If both are not available, the task will be accomplished with the manpower that is available and the training designator will be taken off the transaction.

Input and Evaluation Measurements

The above discussion has presented the mechanics of the primary activities in the workcenter system, and has explicitly shown the range of possible impacts due to different task times associated with the two skill level groups. In order to quantify these impacts, several input requirements are used to define all of the variables which are required to make the decision portion and task time assignment portion of the model work as has been described. After presenting these input measurement requirements, the

statistical measurements used to evaluate the performance of the system will be discussed.

The following are the input measurement requirements of the model:

1. Workorder generation: a measure of the frequency a workorder occurs on a particular aircraft system/component for a given flying schedule and weapons system.

2. For a given system/component, the frequencies for each of the following task classifications for a given flying schedule:

- operational check
- troubleshoot
- unscheduled remove and replace
- scheduled remove and replace
- repair in place/minor maintenance
- cannot duplicate malfunction
- remove and replace to facilitate other maintenance

3. Each task classification listed above also requires the following information:

- percentage of tasks which are priority 1 workorders
- percentage of tasks which are priority 2 workorders
- percentage of tasks which require a 5-level skill ability as a minimum
- percentage of tasks which can allow a 3-level skill ability to accomplish
- percentage of tasks which require a two man team
- percentage of tasks which require one man
- mean task time for 5-levels and the standard deviation
- mean task time for 3-levels and the standard deviation (these task times will equal training task times)
- impact on task time for a two man task being performed by one man

- probability that a particular task will be utilized for training
- specific training task information includes:

    - degree of training workload required by aircraft system, task classification, and number of 3-levels
    - expected number of tasks accomplished per unit of time

- percentage of tasks requiring rework due to a technician's error
- probability that a task will affect the future break rate of an aircraft system due to a technician's error

The workcenter's performance can be measured by indicators which take into account the productive capacity associated with the work force assigned to the workcenter. These indicators are a measure of how well the workcenter is meeting its objectives of minimum through time of workorders through the system. The performance indicators are listed and defined below:

Average workorder backorder time - the average time which the workorder is waiting for the manpower resource to be assigned to the workorder. These statistics are gathered at the interval statistics nodes following the allocate nodes in Figure 2-4.

Average task time - the average time the workorder is in the in-work status. These statistics are gathered at the interval statistic nodes in Figure 2-5.

Average workorder through time - the total time a workorder is in the workcenter subsystem. This statistic is the sum of backorder time and task time. (Note: a general productivity measure is the ratio of the amount of output to the amount of input. In this case, it would be the amount of tasks completed to the number of man-hours expended. This is the reciprocal of the task time statistic; therefore, average task time can be considered a relative measure of productivity.)

Utilization rate - the ratio of resource productive time to resource available time. This statistic is provided internally by the Q-TERT model routines.

One other factor to be measured is the relative amount of time a resource is utilized on a task with a different resource requirement definition (i.e., a 3-level technician performing a task which was originally designated for a 5-level to perform). This indicator will tell whether the 3-level resource is being utilized more than their abilities can allow them to do, or, whether 5-levels are performing more of the easier tasks than they should be doing. If the proper skill level mixture is set up correctly, these indicators will be at their minimal values. A battery of statistics nodes after the allocate nodes shown in Figure 2-6 are used to collect these between statistics on the different routes the tasks can take through the resource pool of manpower.

Summary

This completes the structural model embellishment and measurement requirements necessary for the Q-GERT analysis. It is important to understand that the degree of specificity presented for the objects, attributes, and relationships in this structural model were necessary to capture the dynamic processes of the workcenter system and the impact on workcenter performance due to the manpower resource.

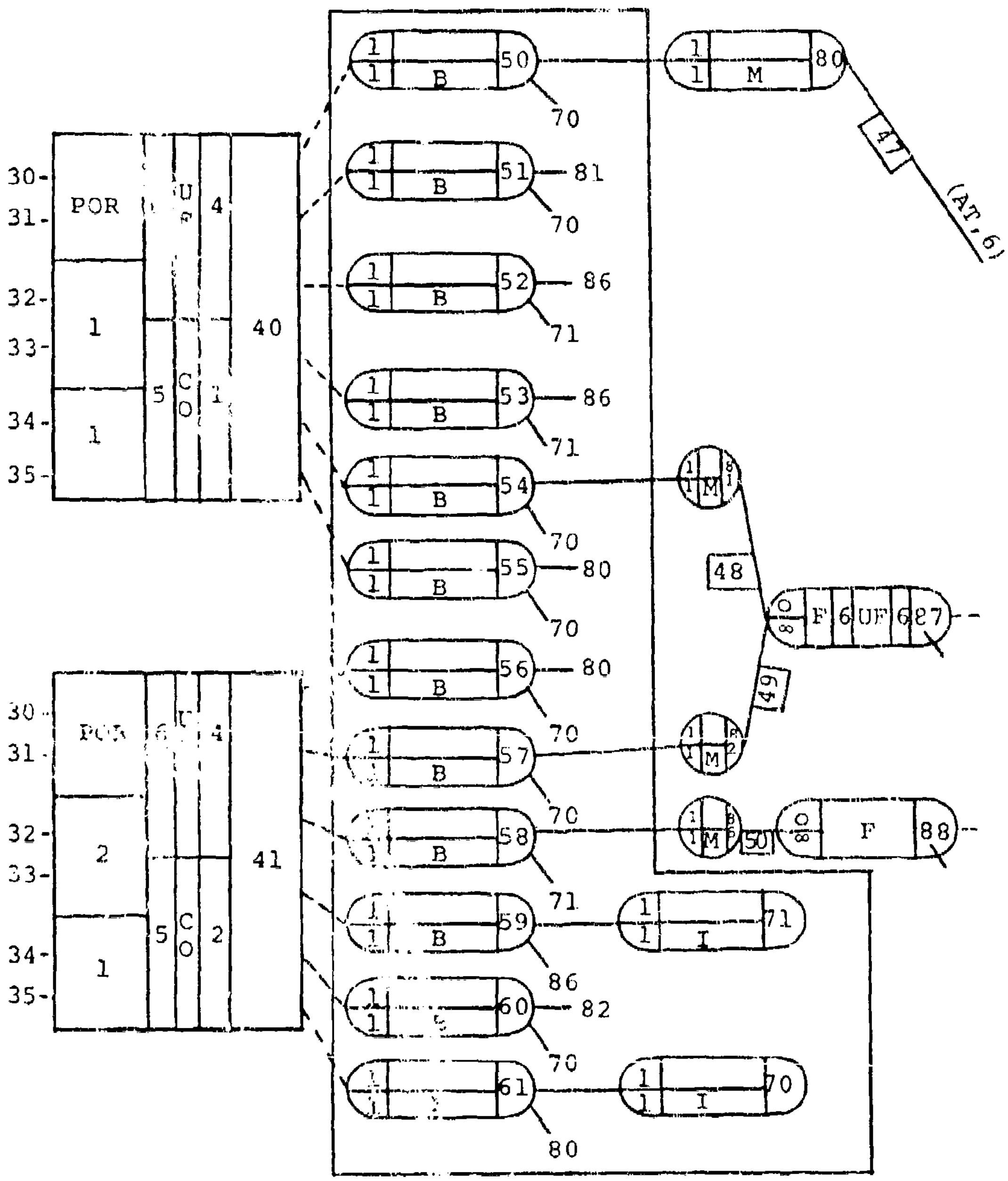

Fig. 2-6. How a Battery of Statistic Nodes Can Be Inserted Into the Q-GERT Structural Model To Measure Workcenter Performance

The emphasis in this chapter has been on developing a conceptual view of the maintenance workcenter system both as a subsystem to the overall maintenance system and environment, and as an independent system with its own objects, attributes, and resources. Using this systems analysis approach, the importance of the maintenance workcenter's goals were clearly defined and related to the managerial decision process used in the workcenter for supporting its goals. With the aid of these concepts and processes, a structural model was developed using Q-GERT and a method was proposed for measuring the performance and capability of the workcenter. In Chapter 3, the applicability and implementation of the above concepts and processes in LCOM will be discussed.

Chapter 3

THE LCOM METHODOLOGY

In Chapter 2, a conceptual framework of how the workcenter operates and how skill level factors influence its operation were discussed. The following discussion will explain how to incorporate the conceptual framework into an LCOM methodology. The flow of this discussion is outlined in Figure 3-1. First a discussion will be presented on how the assignment decision structure can be incorporated into the LCOM network data base, and how the different input measurements listed at the end of Chapter 2 can be included in LCOM simulations. Second, the limitations of LCOM and suggestions for changes which can be made in LCOM to alleviate these limitations will be addressed. Finally, the methodology will be presented in the context of the existing LCOM structure. Specifically, the methodology entails several parallel investigations before actually modifying the LCOM data base to reflect the conceptual framework discussed in Chapter 2. Three major areas were investigated: (1) the relationship between 3-level and 5-level task time; (2) the probability that a task would be performed by a 3-level or 5-level; and (3) the probability of having a training task situation in the workcenter. (The specific workcenter under investigation will be the Flightline

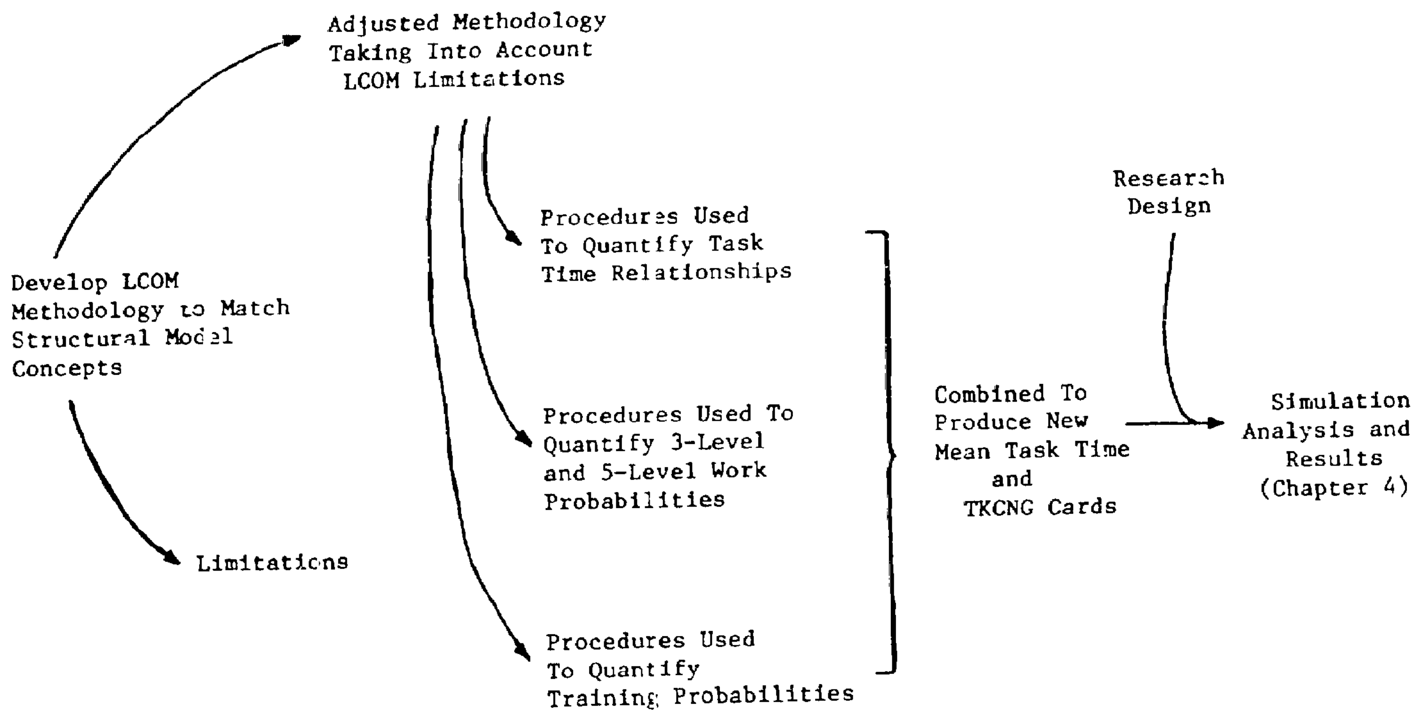

Fig. 3-1. Flow Diagram for the Areas of Discussion in Chapter 3.

Navigation Specialists. This workcenter represents typical workload and manning levels for a majority of workcenters in LCOM.) A detailed discussion of each major area in the methodology will be presented showing the steps leading to the final modified simulation model. The discussion on the relationship between 3-level and 5-level task times will cover the use of regression analysis on task time data obtained from a stratified sample of tasks and task times for the navigation specialist workcenter and the development of a regression predictor model for 3-level task times. The discussion on the probability that a 3-level or 5-level will perform the task will show how the CODAP job description data will be used. Also, a scheme will be presented for adjusting these probabilities with changes in skill mixture conditions. Finally, the discussion on the probability of having a training task situation in the workcenter will assess the relationship of training requirements with the skill mixutre and workload of the workcenter to determine what the training probabilities should be. Each of the major areas in the methodology will then be used to quantify the average mean task time for each task in the workcenter given a specified skill mixture condition. The actual model modifications will be made using the LCOM task change card procedure. Also, a specific research design which will isolate the skill level effects on the workcenter's performance will be presented.

Application of Structural Model to LCOM

The LCOM structure contains the basic mechanisms or procedures for handling the generation and priority assignment of workorders, and the assignment of resources (both manpower and nonmanpower resources). The workorder evaluation activity, resource assignment activity, and task activity, therefore, are present in some form in the LCOM structure. The primary difference between the LCOM structure and the conceptual structure presented in Chapter 2 is that LCOM does not distinguish between the different skill level groups within the manpower resource. Basically, the activities are handled in a different fashion. Instead of processing a workorder through a workcenter, LCOM processes the aircraft through a series of tasks. The task descriptions are input into LCOM by the user and specify the resources that are required. If the resources are available, the task is worked. If not, the task is put on hold. Thus, the LCOM structure is based on a workflow network where each task is described in its corresponding place in the workflow. The flying schedule, which is defined externally from the simulation, places a demand for an aircraft. An aircraft is assigned to this demand, and is placed in the network depending upon what work is required to get the aircraft ready to fly. The aircraft then goes from one task to another based on the sequences specified in the network. When the aircraft is ready to fly, it is at the launch task and flying portion

of the network. Upon return of the aircraft from its mission, failure clocks are checked to determine what systems on the aircraft have failed. The aircraft is then processed through the portions of the network which correspond to the failed system (10:p.2-9).

Figure 3-2 shows how the LCOM network is laid out for the Radio Navigation/Interrogator Set (WUC 71S00) system in the F-4E peacetime model used in this study. The route which the aircraft follows in this section of the model is based on the probabilities that the system will have experienced a particular type of failure which requires specific maintenance actions. These probabilities are shown along the different routes leaving a node and are specified on the forms input. A summary of the different probability options is presented in Table 3-1. The probabilities are set up to capture the same proportion of the various tasks as is experienced in the field and reported in the Maintenance Data Collection system. The various maintenance tasks which are represented in the LCOM network presented above are defined in Table 3-2. When the aircraft reaches a particular task, it requires the resources specified in the input forms. These are annotated as AFSC requirements on the network in Figure 3-2. When the resources are assigned to the task, a task time is assigned by a random draw from the task time distribution defined for that task on the input forms. In summary, the above discussion outlines the basic existing structure

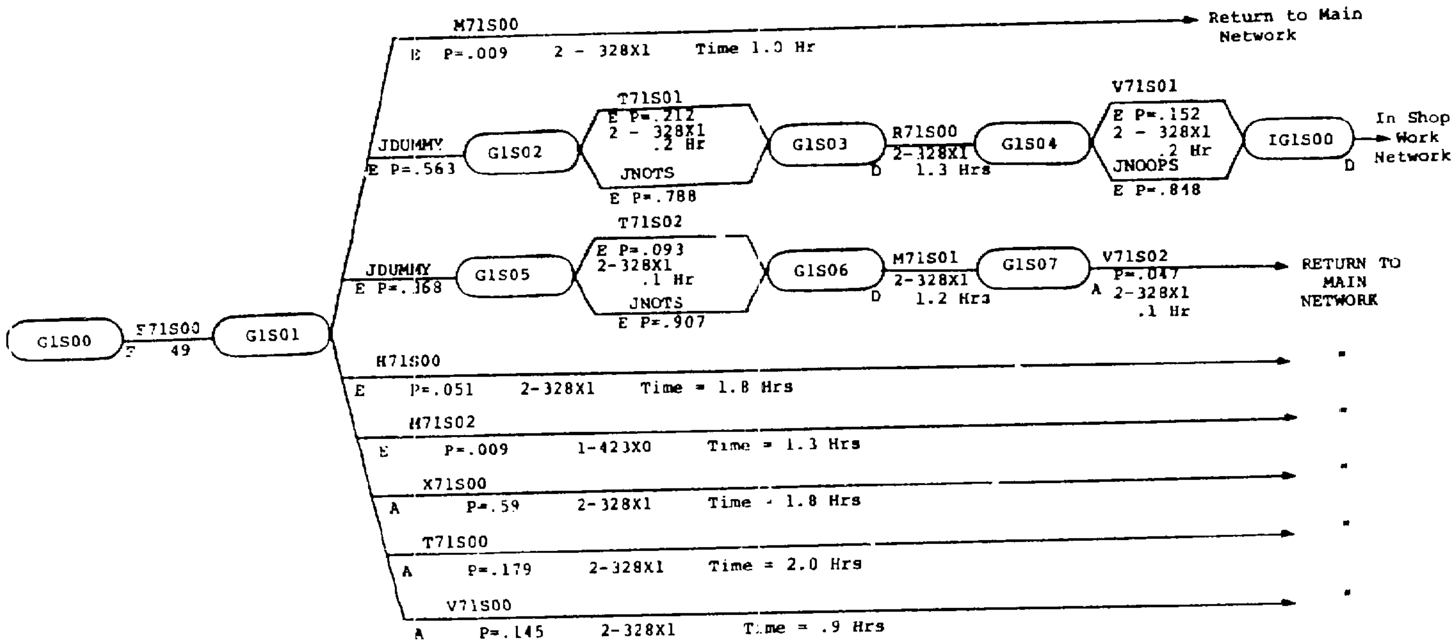

Fig. 3-2. LCOM Network Section from F-4E Data Base for the Radio Navigation/Interrogator Set (WUC 71S00) System

TABLE 3-1

Applicable LCOM Selection Mode Probability Options

SELECTION MODE	DEFINITION
D	Do the task
E	Mutually exclusive selection--one and only one task will be selected.
A	Nonmutually exclusive selection--none, one or more tasks will be selected
F	Selection governed by Failure Mechanism
G	Nonmutually exclusive selection where at least one task will be selected

TABLE 3-2

Applicable LCOM Maintenance Action Codes for On-Equipment Networks

CODE	DEFINITION
F	Failure clock
T	Troubleshoot (successful)
X	Work to facilitate other maintenance
R	Remove and replace component
H	Troubleshoot (can-not-duplicate)
M	Maintenance repair on aircraft
V	Verification check (Ops-check)

of LCOM, and the areas which will be specifically dealt with in developing the methodology in which to incorporate the skill level effects.

Since an LCOM structure already exists which assigns resources when a task is reached in the network, the first step in capturing the decision mechanism of the Q-GERT model is to define two separate manpower resources for each existing task. One would be for the 5-levels and above, and the other would be the 3-levels. In order to do this, two new tasks will have to be created out of the old task; one for each skill level resource. Each new task will have a unique task time distribution associated with its particular skill level resource. This procedure, when applied to the network in Figure 3-2, will result in the network shown in Figure 3-3. The probability that either the 5-level task or 3-level task will be taken is based on the probability that the task will be performed by a 5-level or a 3-level. This is represented by the "E-probabilities" associated with the two different task routes.

The next step in capturing the Q-GERT decision structure is to set up a resource substitution scheme. The model should be able to substitute a different skill level resource for the primary resource when the primary resource is not available. This will allow the work to continue as long as there is someone available from the particular workcenter involved. Resource substitution is possible in LCOM

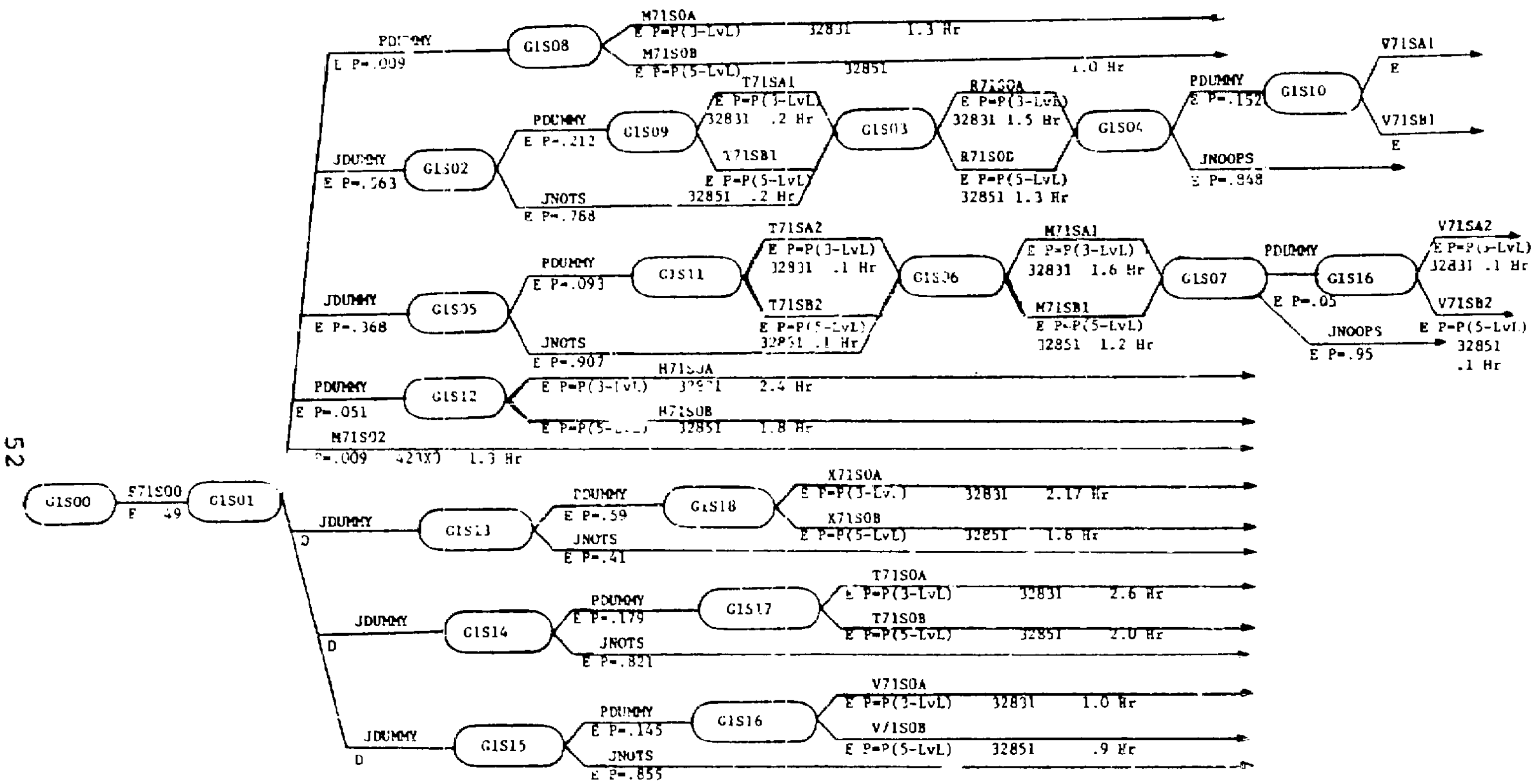

Fig. 3-3. Modified LCOM Network for the Radio Navigation/Interrogator Set Showing How the Tasks Can Be Broken Out Into A 3-LvL Task and A 5-LvL Task

and is done with the Forms 12A. A possible scheme by which resource substitution can be made for two man tasks is shown below for the 328X1 tasks presented in Figure 3-3:

For a 5-level task:

> If 32851 & 32831 & 328A1 & 328B1 are available, then these will be assigned.
>
> Else if 2-32851 & 2-328B1 are available, then these will be assigned.
>
> Else 2-328A1 will be assigned.

For a 3-level task:

> If 32831 & 32851 & 328B1 & 328A1 are available, then these will be assigned.
>
> Else if 2-32831 & 2-328A1 are available, then these will be assigned.
>
> Else 2-328B1 will be assigned.

The 328A1 and 328B1 are dummy resources for the 3-levels and 5-levels, respectively. The purpose behind using these dummy resources is to measure how often the 3-level and 5-level technician is used to perform a task which is not appropriate for his ability level. The substitution scheme also ensures that the 3-level or 5-level technician resources are not available for task assignment when all of the assigned 3-level or 5-level technicians are busy working other tasks. The utilization rate for these two dummy resources will correspond to how busy each individual resource was during the course of the simulation. The 32831 and 32851 resources also correspond to 3-levels and 5-levels, respectively. The utilization rate associated with these

resources will correspond to how often the resources were used in accordance with their abilities. Differences between the utilization rate of the 32831 and 328A1 is a measure of how often the resource's ability was mismatched with the task difficulty. In this case, it would indicate how often the 3-level was sent out on tasks more difficult than the individual was capable of (utilization rate of 328A1 would be greater than the utilization rate of 32831). Such a condition can have implications on the capability of the workcenter. If the skill mixture is such that a 2-328A1 substitution occurs often, it is possible that the task times representing the 3-level capabilities may be too short. In other words, inexperienced and undertrained 3-levels are being sent out to do difficult jobs more often than their capability predicts. The time it takes these 3-levels to do this work will be greater than the 3-level task times used in the LCOM data base developed for this study. Three-level task times are based not only on the time required by a 3-level to perform a task for which the individual has been trained and qualified, but also for which the individual has not had enough experience to become fully proficient.

Figure 3-4 shows how the Forms 12A would be set up in order to accomplish the above resource substitution. However, one major problem remains: when a 3-level substitutes for a 5-level, the task time which is assigned comes from the 5-level's task time distribution. Without the

LOGISTICS COMPOSITE MODEL

SECTION II - SIM
FORM 12 - TAS

Card I.D.		Task I.D.		Task Type	Priority	Task Duration: Mean	Task Duration: Variance	Dist	*	Associated Resource	Resource	C	Qty.	Resource	C	Qty.	Resource	C	Qty.
12		H71S0A		2	1	[illegible].4H	.7ØH	L			3283 1		1	3285 1		1	328A 1		1
		H71S0F	C								328B 1		1						
	A	H71S0A								RCS-1	3283 1		2	328A 1		2			
	A	H71S0F								RCS-2	328B 1		2						
		H71S0E		2	1	1.8H	.52H	L			3285 1		1	3283 1		1	328B 1		1
		H71S0E	C								328A 1		1						
	A	H71S0E								RCS-3	3285 1		2	328B 1		2			
	A	H71S0E								RCS-4	328A 1		2						
		H71S0A		2	1	1.3H	.38H	L			3283 1		1	3285 1		1	328A 1		1
		H71S0F	C								328B 1		1						
	A	H71S0A								RCS-1									
	A	H71S0F								RCS-2									
		H71S0E		2	1	1.ØH	.29H	L			3285 1		1	3283 1		1	328B 1		1
		H71S0B	C								328A 1		1						
	H	H71S0B								RCS-3									
	A	H71S0B								RCS-4									
		H71SA1		2	1	1.6H	.46H	L			3283 1		1	3285 1		1	328A 1		1
		H71SA1	C								328B 1		1						
	A	H71SA1								RCS-1									
	A	H71SA1								RCS-2									
		H71SE1		2	1	1.2H	.35H	L			3285 1		1	3283 1		1	328B 1		1
		H71SE1	C								328A 1		1						
	A	H71SA1								RCS-3									
	A	H71SE1								RCS-4									

Fig. 3-4. Resource Substitution Scheme as Input on the Forms 12A

ability to assign a 3-level task time during a substitution, the procedure will invalidate the model as conceptualized in Chapter 2. The actual status of the resources will not reflect the correct task times. In order to alleviate this shortcoming in LCOM, major revisions would have to be made to the LCOM software. Such revisions are beyond the scope of this research effort. To stay within the limitations of the existing LCOM structure, the following assumption must be made: the probabilities developed from CODAP data, for a 3-level performing the task and a 5-level performing the task, will approximate the necessary state of resource availability. This assumption will allow the development of a methodology that does not require resource substitution. Procedures used in Howell's dissertation and those used routinely by manpower personnel involve weighting task times for two like tasks that run parallel to each other by the probability that the task will occur. The two tasks are then merged into one new task, with the sum of the weighted mean task times as the new mean task time.

The procedure described above can easily be applied to the two task structure developed in Figure 3-3. It involves multiplying the probability that a 5-level will perform the task to the 5-level mean task time and adding the probability that a 3-level will do the task multiplied to the 3-level mean task time. The resultant task time is the mean task time of the two tasks acting together. The

new mean will be input to the LCOM data base by use of the TKGNG change card procedure provided by the LCOM software (2:p.7-15).

With the basic methodology now established, the technician error impacts and training impacts will be addressed. As noted in Chapter 2, technician errors can cause the task to be reworked, or the failure rate to increase. The data base of the existing model already has some of these effects built into it. The actual data used in developing the data base reflect the errors which the maintenance technician made during the time the data were collected. This error factor is not discernible in the data presently used in the LCOM model. Any changes to the proportion of tasks performed or break rates represented by the failure clocks in the model, will give a different set of task proportions and failure rates than those which have already been validated for the model. Thus, without being able to discern the exact effects in the current data base nor understand how these error effects can change with skill mixture, any increase in failure rates or number of tasks which could be interpreted as due to an increase in the number of 3-levels in the shop, could invalidate the model. An investigation of this problem will not be included in this research but deserves further, future research.

The training impacts discussed in Chapter 2 can be handled by determining the probability that the task will be

utilized in a training situation. Each existing task can be converted to three parallel tasks: (1) one for the 5-level situation; (2) one for the 3-level situation; and (3) one for the training situations as shown in Figure 3-5. By first taking into account the training requirements and then accounting for the remaining 5-level and 3-level situations in which training does not occur, the probabilities (Prob) for the three tasks are as follows:

training task = Prob(training)
5-level task = (1 - Prob(training))Prob(5-level)
3-level task = (1 - Prob(training))Prob(3-level)

Discussions with several maintenance personnel have provided support for assuming that training task times and 3-level task times are the same. Thus, the new mean task time for all three tasks taken together can be represented as:

(Prob(3-level time))(3-level mean)
+ (Prob(5-level time))(5-level mean)

where

Prob(3-level time) = Prob(training) + (1-Prob(training)) * Prob(3-level)
and Prob(5-level time) = (1-Prob(training))Prob(5-level)

With the methodology now adjusted for training effects and the error effects being represented to a certain extent in the existing data base, the three major areas in the overall methodology will not be discussed. First, the relationship between 3-level and 5-level task times will be presented. Next, an explanation will be presented on how to

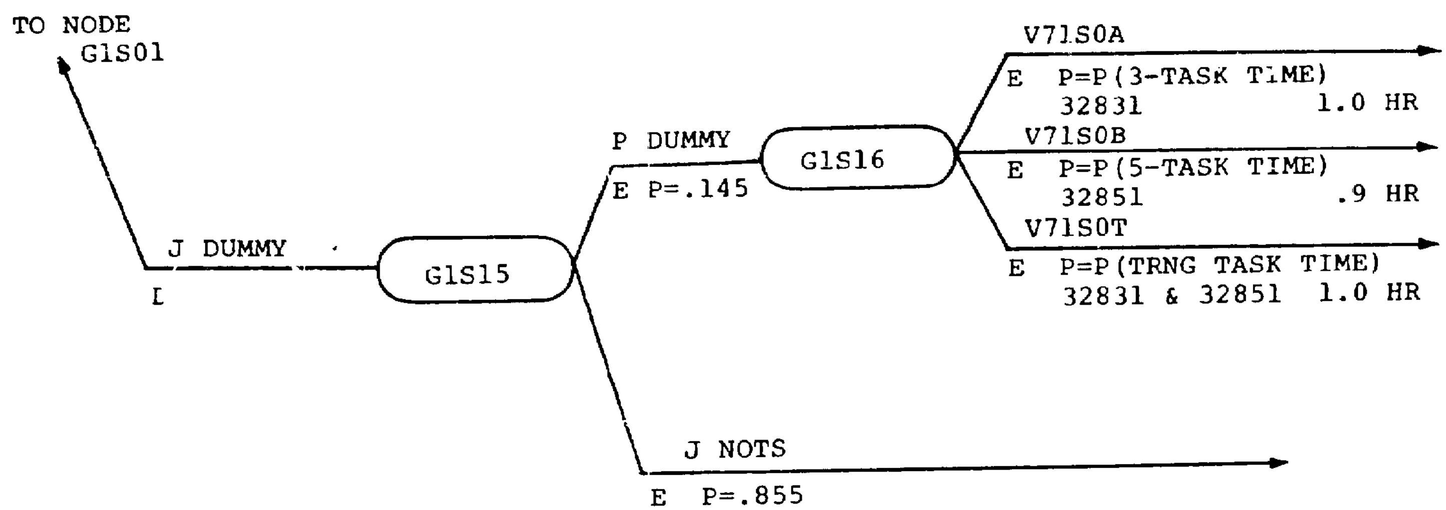

Fig. 3-5. Sample of How the LCOM Network Can Be Broken Out to Incorporate Training Tasks Along With the 3-Level and 5-Level Tasks

obtain the probability that a task will be performed by a 3-level or 5-level using the CODAP information. Finally, a discussion will be made on how the training load can be assessed as a function of the number of 3-levels and the specific task performed. These training factors will determine the probability that the task will be utilized for training.

Procedures for Quantification of 3-Level Task Times

The relationship between 3-level and 5-level task times reflect the difference in time it takes a 5-level technician to do the task as opposed to a 3-level technician because of the difference in their ability levels. The task times presently used in the LCOM F-4E model reflect a 5-level skill ability. Hence, it is necessary to measure the 3-level task times for each task or define the relationships between the 3-level and 5-level task times. (Specifically, a 3-level task time is the time it takes a qualified 3-level to perform the task. A "qualified" 3-level has obtained sufficient training on the task and can now perform the task without the help of a trainer.) Due to the large number of measurements required to obtain a 3-level task time for each task, a stratified sampling approach will be used to gather task times on 5-levels and 3-levels for the various systems and tasks worked on by the subject workcenter. A regression analysis will be performed on the sample data to develop a

regression predictor model for 3-level task times. The independent variable inputs to the regression model will involve indicator variables for the various systems and task types, and a quantitative variable for 5-level task times. This regression model structure with 3-level task times as the dependent variable is:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 + \beta_6 X_6 + \beta_7 X_7 + \beta_8 X_8 + \beta_9 X_9 + \beta_{10} X_{10} + \varepsilon_i$$

The X_1 to X_5 vairables are the indicator variables for each system, the X_6 to X_9 variables are indicator variables for each task type, and X_{10} is the quantitative variable for the 5-level task times. Table 3-3 shows the corresponding relationship between the indicator variables and the specific tasks and systems worked by the subject workcenter of this thesis--the navigation specialist flightline workcenter (328X1).

Procedure for Quantification of Skill Level Work Probabilities

The next measurement to explain is how to obtain the probability that a specific task will be worked by a 3-level or a 5-level. This will be accomplished using the information from CODAP. To develop these probabilities, one must be able to capture the work which is normally done by a 3-level and by a 5-level. The work which 3-levels accomplish

TABLE 3-3

Indicator Variable Relationships with Specific NAV Systems and Tasks

F-4E Navigation System		LCOM Action Codes		Corresponding Indicator Variable
71L00	Integrated Electronic Central - TACAN			None
71M00	Integrated Electronic Central - UHF Radio			X_1
71S00 & 71V00	IFF Interrogator Set			X_2
71T00	MARK XII IFF Equip			X_3
72300	Radar Altimeter			X_4
72500	Radar Transponder			X_5
		H	Troubleshoot, No Defect Noted	X_6
		M	Maintenance Repair	X_7
		R and X	Remove and Replace	X_8
		T	Troubleshoot, Defect Found	X_9
		V	Operational Check	None

will reflect their ability level and how far they have progressed through their training requirements. Inutitively, therefore, the work which is simple and routine will be accomplished more often by new 3-levels, with more complex tasks being added to the 3-level's workload as he advances towards becoming a 5-level.

The CODAP surveys were developed to specifically characterize the workload of particular occupations. The first step involves developing, within the practicality of having a useful survey instrument, a job inventory survey for an occupation which lists all possible tasks. The job inventory survey is then administered to the technicians within the occupation. The information from the surveys can be displayed and analyzed in several different ways to focus on various characteristics of the occupation. The particular information display of interest to this thesis is the Group Job Description By Tasks. An example of a Group Job Description Display is presented in Figure 3-6. The key statistic in this display is the "average percent time spent by all members." This column of percentages adds up to 1.00 and each percentage can be likened to the probability that a member from this group will be performing the associated task. The information can also be broken out by skill level groups. An example of the skill level groupings is shown in Table 3-4. This table is actually a set of conditional probabilities for each skill group; given a skill group, the

3 SKILL LEVEL AMN W/ CAFSC 32631 WORKING ON F-4 SPL300 PAGE 1

JOB DESCRIPTIONS OF 3,5,7 SKILL LEVEL AMN - CONTROL AFSC 328X1 MAINTAINING F-4
THE SAMPLES OF AIRMEN WORKING ON F-4'S INCLUDES F-4C,4D,4E,4F,4G,4L,4M & RF-4C

DUTY JOB DESCRIPTION	CASES	TASKS	DUTIES	MBRS
	1795	960	18	48

CUMULATIVE SUM OF AVERAGE PERCENT TIME SPENT BY ALL MEMBERS
AVERAGE PERCENT TIME SPENT BY ALL MEMBERS
AVERAGE PERCENT TIME SPENT BY MEMBERS PERFORMING
PERCENT OF MEMBERS PERFORMING

D-TSK	DUTY/TASK TITLE	PERCENT OF MEMBERS PERFORMING <*>	AVERAGE PERCENT TIME SPENT BY MEMBERS PERFORMING	AVERAGE PERCENT TIME SPENT BY ALL MEMBERS	CUMULATIVE SUM OF AVERAGE PERCENT TIME SPENT BY ALL MEMBERS
H	PERFORMING GENERAL AIRCRAFT NAVIGATIONAL SYSTEMS MAINTENANCE	97.92	13.48	13.20	13.20
L	MAINTAINING AIRBORNE IDENTIFICATION SYSTEMS	81.25	19.84	16.12	29.32
E	PERFORMING MAINTENANCE ADMINISTRATIVE FUNCTIONS	81.25	8.33	6.77	36.09
M	MAINTAINING TACTICAL AIR NAVIGATION (TACAN) SYSTEMS AND ASSOCIATED INSTRUMENTATION EQUIPMENT	75.00	15.56	11.67	47.76
G	PERFORMING ASSIST TASK QUALIFICATION TRAINING (ATQT) DUTIES	75.00	3.88	2.91	50.67
K	MAINTAINING RADIO/RADAR ALTIMETERS	68.75	16.49	11.33	62.01
I	MAINTAINING INSTRUMENT LANDING SYSTEMS (VOR/ILS)	54.17	12.15	6.58	68.59
R	MAINTAINING FORWARD-LOOKING (FLR), MULTI-MODE, AND TERRAIN-FOLLOWING RADAR (TFR) SYSTEMS	43.75	37.06	16.22	84.81
F	PERFORMING CROSS UTILIZATION TRAINING (CUT) DUTIES	39.58	8.30	3.28	88.09
B	DIRECTING AND IMPLEMENTING	25.00	1.96	.49	88.58
D	TRAINING	22.92	1.20	.27	88.86
O	MAINTAINING AUTOMATIC DIRECTION FINDER (ADF) SYSTEMS	20.83	5.90	1.23	90.09
C	EVALUATING AND INSPECTING	18.75	4.10	.77	90.86
A	ORGANIZING AND PLANNING	18.75	3.26	.61	91.47
N	MAINTAINING LONG RANGE NAVIGATION (LORAN) SYSTEMS AND OMEGA SYSTEMS	16.67	30.74	5.12	96.59
J	MAINTAINING RENDEZVOUS RADAR BEACON SYSTEMS	14.58	4.39	.64	97.23
P	MAINTAINING SEARCH RADAR SYSTEMS	12.50	17.40	2.18	99.41
Q	MAINTAINING STATION KEEPING EQUIPMENT (SKE)	6.25	8.34	.52	99.94

Fig. 3-6. Job Description of the 3-Level Skill Group Working on All F-4 Models in the 328X1 Career Field

TABLE 3-4

Percent Time Spent Performing Duties by Skill Level Groups in the 328X1 Career Field

DUTY	TOTAL SAMPLE (N=1,796)	DAFSC 32831 (N=204)	DAFSC 32851 (N=946)	DAFSC 32871 (N=593)	DAFSC 32899 (N=33)	CEM CODE 32900 (N=10)
SUPERVISORY AND TRAINING:						
A ORGANIZING AND PLANNING	3	*	1	6	19	23
B DIRECTING AND IMPLEMENTING	6	1	2	12	28	34
C EVALUATING AND INSPECTING	3	*	1	6	19	22
D TRAINING	3	1	2	6	7	6
ADMINISTRATIVE:						
E PERFORMING MAINTENANCE ADMINISTRATIVE FUNCTIONS	8	6	6	11	16	10
NON-AVIONICS NAVIGATION SYSTEMS MAINTENANCE:						
F PERFORMING CROSS UTILIZATION TRAINING (CUT) DUTIES	3	3	3	2	1	1
G PERFORMING ASSIST TASK QUALIFICATION TRAINING (ATQT) DUTIES	3	2	3	2	1	1
TECHNICAL:						
H PERFORMING GENERAL AIRCRAFT NAVIGATIONAL SYSTEMS MAINTENANCE	9	13	10	8	2	*
I MAINTAINING INSTRUMENT LANDING SYSTEMS (VOR/ILS)	10	13	12	8	2	1
J MAINTAINING RENDEZVOUS RADAR BEACON SYSTEMS	2	3	2	2	*	*
K MAINTAINING RADIO/RADAR ALTIMETERS	6	8	7	4	1	*
L MAINTAINING AIRBORNE IDENTIFICATION SYSTEMS	14	14	16	11	2	*
M MAINTAINING TACTICAL AIR NAVIGATION (TACAN) SYSTEMS AND ASSOCIATED INSTRUMENTATION EQUIPMENT	10	12	12	7	1	*
N MAINTAINING LONG RANGE NAVIGATION (LORAN) SYSTEMS AND OMEGA SYSTEMS	2	3	2	2	*	*
O MAINTAINING AUTOMATIC DIRECTION FINDER (ADF) SYSTEMS	3	3	4	2	*	*
P MAINTAINING SEARCH RADAR SYSTEMS	11	12	12	8	1	*
Q MAINTAINING STATION KEEPING EQUIPMENT (SKE)	2	1	2	1	*	0
R MAINTAINING FORWARD-LOOKING (FIR), MULTIMODE, AND TERRAIN-FOLLOWING RADAR (TFR) SYSTEMS	2	5	3	2	*	0

* INDICATES LESS THAN .5 PERCENT

probability that a member of the group will be performing a particular task is the average percent time spent on t e task y the group.

If Table 3-4 is viewed as a conditional probability table, the marginal probabilities of the skill level groups represent e proportion of tasks performed by each skill level grou to the combined tasks performed by all the members. With these marginal probabilities, it is possible to develop a joint probability table using the probability multiplication theorem:

$$P(A_i|B_j)P(B_j) = P(A_i \cap B_j)$$

In the equation, $P(B_j)$ is the marginal probability for each skill group based on the proportion of the work force the skill group represents, and $P(A_i|B_j)$ is the conditional probability that task A_i will be worked given group B_j. With the joint probability table constructed, it is possible to calculate the conditional probabilities given each task with the following version of the multiplication theorem:

$$P(B_j|A_i) = \frac{P(A_i \cap B_j)}{P(A_i)}$$

In this version, the margi l probabilities for the tasks A_i are given as the pe me spent on the particular task by all the skill groups ined. The conditional probability, $P(B_j|A_i)$, gives the probability that a task

will be performed by a particular skill group B_j, given a particular task A_i. This is the type of information required for input into the LCOM model since it gives the probability that a task will be performed by a 3-level or 5-level.

With the basic relationships defined for the tasks and skill level groups represented in CODAP, all that remains is to match the tasks described and used in LCOM to the tasks described in CODAP. Unfortunately, a one for one mapping relationship between the LCOM tasks and CODAP tasks does not exist. A proposed mapping is presented in Table 3-5. Note how the LCOM tasks have been broken down into 6 systems and 4 task type groups. Within this framework, all of the CODAP tasks which fall into each category are listed (Appendix B gives a description for each CODAP numeric code used). Also note that CODAP has a set of general maintenance (GMT), trouble shooting (TGST), and verification tasks (GVT). Each of these will be applied across all LCOM systems in the general task area. Thus, for each system/group in LCOM, the percent time spent will be the sum of the corresponding CODAP tasks plus a weighted proportion of the applicable general CODAP task groups. The weighted proportion will be figured using data from preliminary LCOM simulation runs. The number of times each task is expected to be performed will be drawn from the average number of tasks hit during six simulation runs. Each task's average number of hits will be multiplied by its mean task time to give the expected

TABLE 3-5

Proposed LCOM t[illegible] CODAP Mapping Scheme

SYSTEM	LCOM MAINT ACTION CODE	SYSTEM RELATED CODAP CODES	GENERAL RELATED CODAP CODES
71L00 Integrated Electronic Central-TACAN	H & T M R & X V	516 to 518 492, 493 502 to 515 494 to 501	28.93% GTST 34.54% GMT N/A 33.52% GVT
71M00 Integrated Electronic Central-UHF Radio	H & T M R & X V	183 to 192 164, 165, 166 171 to 182 167 to 170	.83% GTST 1.47% GMT N/A .52% GVT
71S00 & 71V00 IFF Interrogator Set	H & T M R & X V	417 N/A 408 to 412, 415 404 to 407	62.76% GTST 53.89% GMT N/A 56.15% GVT
71T00 IFF MARK XII	H & T M R & X V	417 403, 416 413, 414 404 to 407	62.76% GTST 3.3% GMT N/A 56.15% GVT
72300 Radar Altimeter	H & T M R & X V	373 361, 362 366 to 372 363, 364, 365	5.21% GTST 4.35% GMT N/A 7.1% GVT
72500 Radar Transponder	H & T M R & X V	343 331 336 to 342 332 to 335	2.28% GTST 2.45% GMT N/A 2.71% GVT
G[illegible]l Trouble-s[illegible] Tasks GT[illegible] (H & T)	All H & T	263 to 265	N/A
General Mainte-nance Tasks GMT [illegible]	All M	224, 229, 230, 232, 250 to 252, 2[illegible] to 261, 266	N/A
General [illegible]fi-cation [illegible] GVT [illegible]	All V	79	N/A

H & T = [illegible]shoot; M = Maintenance; R & X = Remove & Replace; V = Operationa[illegible] [illegible]cks

time spent on that task for an entire simulation period. These expected task times will be grouped according to the LCOM system and task categories shown in Table 3-5. The proportion of time spent in an entire simulation period for each system/group will be figured by taking the time spent for one system/group and dividing it by the sum of all expected times across all systems for that group of tasks.

Once the mapping is complete, a Fortran program will be used to generate the probability that a 3-level or 5-level will perform the tasks within each system/group combination. Different marginal probabilities for the skill groups, $P(B_j)$, will be used for each skill mixture combination and a new joint probability table developed for each skill mixture. Then, as previously described, the new conditional probability table will be constructed. The new set of probabilities developed for each skill mixture will be used to predict whether a 3-level or 5-level will perform the task and will reflect the relative changes in manning of one skill level group over the other. Thus, if the relative number of 3-levels in the workcenter increases, their share of the workload should also increase, but only as much as their ability level allows. This relationship is inherent in the CODAP data since the percent time which group members spend on a particular task reflects the average ability of the members on a particular task.

Procedure for Quantification of Training Probabilities

The final measure required to complete all necessary inputs to the LCOM methodology is the assessment of the OJT workload and determination of the probability that a task will be used for training. A restriction which manpower personnel at TAC must deal with in LCOM is that the work force composition in LCOM represents the average status of personnel assigned to the workcenter over time (3). Although training requirements quite often decrease as 3-levels gain experience and increase as new 3-levels are assigned, these abrupt changes in personnel status and training loads cannot be represented in LCOM without violating the above constraint. Therefore, in order to model the impact of these changes, a more general view of the OJT workload which focuses on the maximum training load which could be encountered is required. The basic assumption used in developing this general view of the OJT workload is that a 3-level must receive a certain amount of OJT each month in order to progress satisfactorily in his training program. With this assumption, the OJT workload can be quantified by assessing how many tasks out of each system/group (defined earlier) are required to be used for training in order to qualify the average 3-level in these tasks, and by assessing how many months it will take to fully qualify the 3-level in these tasks. With these two assessments, the maximum number of

tasks required for training a 3-level during the simulation time period, is defined by the following relationship:

$$\frac{\text{(simulation time period)}}{\text{(average time to qualify)}} \left(\begin{array}{l}\text{number of tasks} \\ \text{required for training}\end{array}\right)$$

The above relationship represents the maximum training workload which the workcenter could experience in the training progression of its 3-levels. By incorporating the relationship into the LCOM methodology, the maximum training effects will be obtained.[1] Thus to obtain the probability that the tasks defined for each system/group will be utilized for training during the simulation time period, the calculation is defined as:

$$\text{Prob(training)} = \frac{\left(\begin{array}{l}\text{maximum number of} \\ \text{tasks required per} \\ \text{3-level for training}\end{array}\right)\left(\begin{array}{l}\text{number of 3-levels} \\ \text{in the workcenter}\end{array}\right)}{\left(\begin{array}{c}\text{expected number of tasks to occur} \\ \text{in the simulation}\end{array}\right)}$$

The data which was used to weight the CODAP general task groups will be utilized here to give a measure of the "expected number of tasks to occur in the simulation."

---

[1]Assuming that new 3-levels rotate into the workcenter on a routine basis (so the training workload faced by the workcenter stays fairly constant from one month to the next), the following relationship may be appropriate to quantify the average number of tasks for training a 3-level during the simulation time period:

$$\text{(simulation time period)} \frac{\left(\begin{array}{c}\text{Number of tasks required} \\ \text{for training}\end{array}\right)}{\text{(average time as a 3-level)}}$$

Combined Procedures to Form LCOM Methodology

The procedures outlined above complete the discussion of the final embellishments to the methodology. They included establishing the relationship between 3-level and 5-level task times, and explaining how to obtain the probability that a task will be accomplished by a 3-level or 5-level, and how to obtain the probability that a task will be utilized for training. Figure 3-7 summarizes how the steps in the methodology lead to developing the task change cards necessary for modifying the LCOM data base.

Research Design

The LCOM methodology outlined above shows how a workcenter's skill level mixture can be input as a controllable, endogenous variable in LCOM simulations. A research design will now be presented which will isolate the skill mixture effects on the workcenter's performance, specifically for the flightline 328X1 navigation specialist shop (on-equipment work), in the LCOM F-4E model.

A full factorial research design will be accomplished with the two factors shown in Table 3-6. The factors are the number of technicians assigned to the workcenter, and the skill mixture. Three levels of workcenter manning will be used: 6, 8, and 10, along with ten levels of assigned 3-levels. These manning levels were chosen due to their appropriateness in handling the workload generated by the

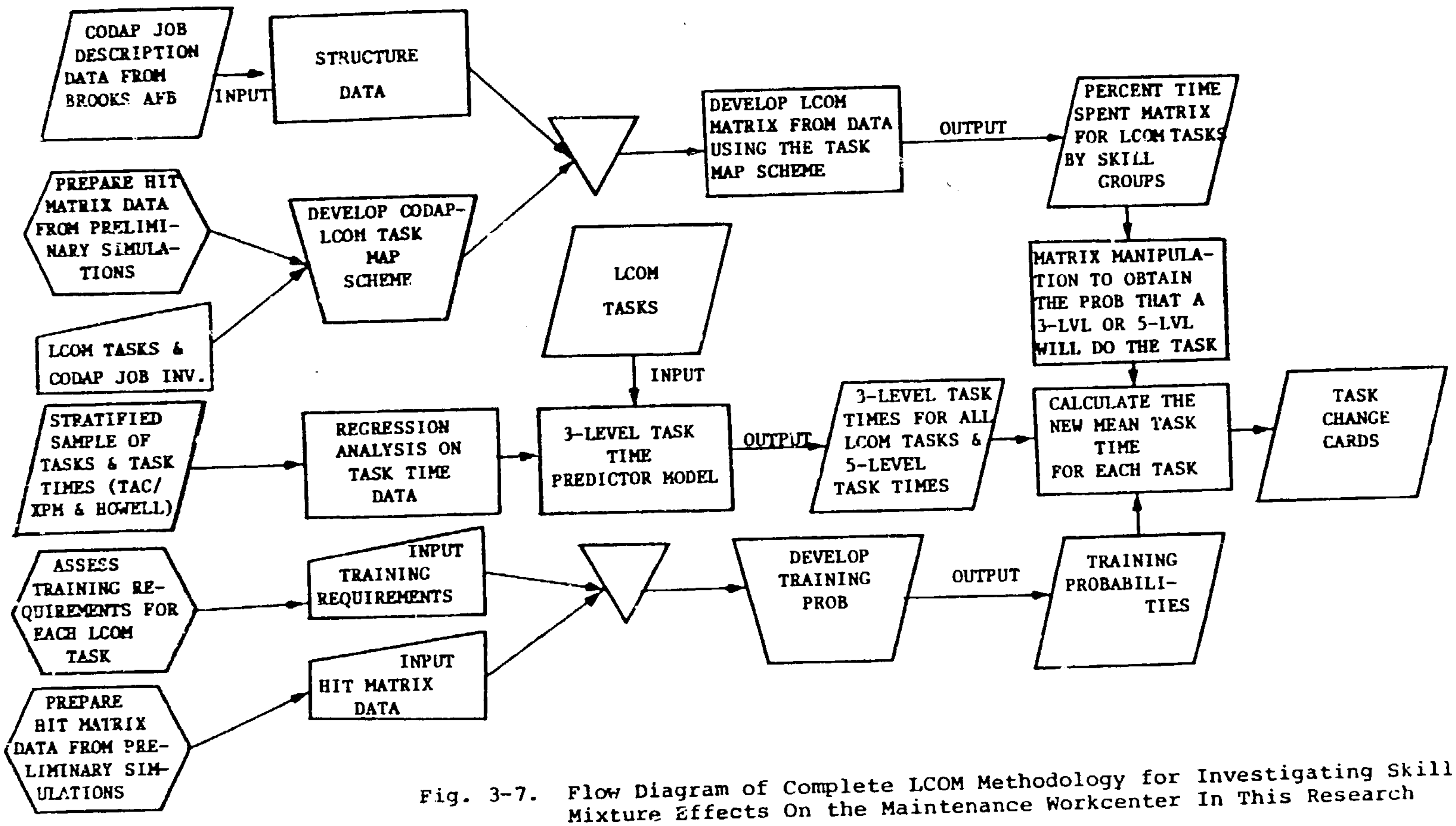

Fig. 3-7. Flow Diagram of Complete LCOM Methodology for Investigating Skill Mixture Effects On the Maintenance Workcenter In This Research

flying scenario used in this simulation. The skill mixture factor will involve multiple levels where skill mixture is defined as:

$$\text{Skill mixture} = \frac{(\text{number of 3-levels})(3) + (\text{number of 5-levels})(5)}{(\text{total number of workers})}$$

The two factor design is shown in Table 3-6. Statistics will be gathered in 10 day intervals over each 60 day simulation in order to obtain six repetitions of data points for each factor combination.

Extraneous variance in the model will be controlled partially by keeping shift structures for a given manning level the same, allowing for unlimited nonmanpower resources, and unlimited manpower resources for all other workcenters except the flightline 328X1 navigation specialists. Another controlled condition is the flying schedule, which will be identical for all simulation runs. The scenario used in the flying schedule is presented in Appendix C. Finally, the random number generator's seed values will also be held constant for all simulations. To alleviate startup problems, a 10 day warm-up period has been established by TAC manpower as being adequate for this F-4E model.

The skill mixutre variable for the simulation run will be changed by adjusting the marginal probabilities of the skill level groups using the CODAP-LCOM conditional probability method discussed earlier. A set of task time

TABLE 3-6

Two Factor Research Design Scheme for Assessing the Impact of Skill Mixture on the Workcenter's Performance

Total Number Workers	Number of 3-Levels 0	1	2	3	4	5	6	7	8	9	10	
6	X 5.0	X 4.67	X 4.33	X 4.0	X 3.67	X 3.33	X 3.0	0	0	0	0	Skill mixture
8	X 5.0	X 4.75	X 4.50	X 4.25	X 4.0	X 3.75	X 3.50	X 3.25	X 3.0	0	0	Skill mixture
10	X 5.0	X 4.8	X 4.6	X 4.4	X 4.2	X 4.0	X 3.8	X 3.6	X 3.4	X 3.2	X 3.0	Skill mixture

change cards will be generated and input into the main simulation program used to run the LCOM simulation.

Upon completion of all simulations, the following statistics will be gathered for each 10 day interval:

INPUT VARIABLES

1. number of people
2. skill mixture
3. simulation 10 day period (1 thru 6)

MAIN SIMULATION STATISTICS (level 1 report)

4. number of sorties flown
5. % operationally ready rate
6. sortie rate
7. flying hours
8. utilization rate
9. man-hours per flying hour

POST PROCESSOR STATISTICS

10. total man-hours
11. tasks completed
12. total backorders
13. average tasks in backorder
14. average backorder duration
15. maximum backorder duration
16. total man-hours backordered

In addition to the above, a productivity statistic will be developed by taking the number of tasks completed and dividing it by total man-hours used.

After a preliminary screening to ensure the veracity of the data, regression analysis with different combinations of dependent (Y) and independent (X) variables will be made using the following regression model:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \varepsilon_i$$

A different version of the regression model will be developed using each of the following LCOM statistics as a unique dependent variable:

- utilization rate
- total man-hours
- total backorders
- average tasks in backorder
- average backorder duration
- total man-hours backordered
- productivity statistic

For the independent variables in the regression model, X_1 will be the number of technicians assigned to the workcenter, X_2 will be the skill mixture for the workcenter as defined earlier, and X_3 and X_4 will be one of the following LCOM statistics:

- sorties
- sortie rate
- flying hours
- tasks completed

These four statistics are used in the regression models as possible blocking factors for workload. The blocking factor is necessary to eliminate the variability in the dependent variable attributable to the changing workload of the workcenter from simulation to simulation. Any autocorrelation effects on the regression model due to high correlation between these blocking factors will be evaluated and only the most significant variables will be used.

From the regression analysis, the impact and relationship which skill mixture has with the dependent variables will be assessed. These results are presented in Chapter 4 along with an analysis of each portion of the LCOM methodology.

Summary

The purpose of this chapter was to show how the conceptual framework developed in Chapter 2 could be applied in an LCOM methodology. The first method proposed for accomplishing this involved taking each existing task in the LCOM data base and representing it by two tasks--one for each skill level group. However, this method proved unfeasible since the substitution scheme used by the LCOM software does not allow for changing the task time distribution to match the substitute resource's capabilities. To stay within the present LCOM software ability and network structure, the following assumption was made: the probabilities of a 3-level or 5-level doing the task can be determined and their combined weighted, average task times used to adequately capture the work force status at any one point in time. Based on this assumption, the remaining methodology considered the three major areas listed below.

1. A regression model method was developed to capture the relationship between 3-level and 5-level task times.

2. Data provided by CODAP on the percent time spent by all members of a specific skill level group on particular tasks was used to construct joint and conditional probability tables. Based on the particular skill level mixture, the conditional probability table gave the probability that a task would be performed by a 3-level or 5-level. A

scheme was also presented on how to interface LCOM tasks with CODAP tasks.

3. A method was presented for determining the maximum training workload in the workcenter for each system/task group combination. From this training workload calculation, the probability of having a training task situation in the workcenter was explained by taking the number of 3-levels requiring training for a group of tasks, and dividing by the expected number of times the task will occur during the simulation.

With the overall methodology established, a flow chart was presented which described how each procedure would be used to develop the modified LCOM data base. Finally, the research design which will be used to isolate the skill mixture effects on the workcenter's performance over several skill mixture and workcenter manning combinations was presented. In Chapter 4, the simulation findings and analysis will be discussed.

Chapter 4

ANALYSIS AND FINDINGS

This chapter will analyze the overall results of the research design and the three major areas of the LCOM methodology development: (1) the 3-level task time relationship with 5-level task times; (2) LCOM-CODAP mapping and methodology for developing the probability that a task will be performed by a 3-level or 5-level; and (3) the development of the training probabilities for each task. The major areas of the LCOM methodology will be discussed first.

Analysis of Task Time Quantification Procedures

A stratified sample of tasks within the six major aircraft systems worked by the 328X1 specialist was obtained from TAC/XPM (3). This information was added to a sample of tasks taken from Howell's dissertation and provided a total of 39 sample data points. Each sample data point reflected the system, task group, 5-level task time and the 3-level task time. The data was arranged using a regression scheme consisting of indicator variables and quantitative variables as presented in Chapter 3. Appendix D shows the values for each variable as input to the regression analysis program. The result of the regression analysis gave the following regression model:

$$Y = (-.087) + (-.216)X_2 + (.218)X_5 + (.092)X_6$$
$$+ (.149)X_7 + (-.139)X_8 + (1.453)X_{10} + (-.643)X_{11}$$

This regression model showed an R^2 value of .988 which indicates that almost all of the variability in the 3-level task times can be attributed to the above independent variables. These variables represent the following systems, tasks, and quantities.

$X_2 \Rightarrow$ IFF Interrogator Set (WUC's 71S00 and 71V00)

$X_5 \Rightarrow$ Radar Transponder System (WUC 72500)

$X_6 \Rightarrow$ Troubleshoot, no defect (Action code H)

$X_7 \Rightarrow$ Maintenance Repair (Action code M)

$X_8 \Rightarrow$ Remove & Replace (Action codes R and X)

$X_{10} \Rightarrow$ 5-level task time

$X_{11} \Rightarrow$ Indicator variable for those tasks less than .5 Hrs (This variable was added to help predict the lower task times)

The actual output from the Statistical Package for Social Sciences (SPSS) computer run is included in Appendix D. In order to verify that this regression model meets the necessary regression constraints of normality and constancy of vairance of the error terms, the following tests were conducted. A Kolomorgov-Smironov test for determining the normality of the standardized residuals concluded that they

are normal with a .049 significance level. Also the residuals displayed constancy of error variance behavior when plotted out, and passed a runs test for randomness.

The above regression model was used as a predictor model for the 328X1 on-equipment tasks in the LCOM F-4E data base. The result of the predictor model is shown in Table 4-1. An examination of these values shows that the 3-level task times predicted for the majority of 5-level task times less than 0.5 hours are outside the range of the predictor model. Apparently, these task times (less than 0.5 hours) are so small, that the predictor model cannot distinguish the increase of the 3-level time over the 5-level time. One possible explanation is that the task time relationship exhibits a nonlinear relationship below 0.5 hours, and perhaps not enough data points were present at the low end of the task time spectrum to fully distinguish the relationship. Therefore, the tasks which were outside the predictive capability of the model will be considered equal to the 5-level task times, since any changes in these task times would be very small, and essentially equal.

Analysis of the Skill Level's Work Probability Quantification Procedures

The second major area in the LCOM methodology is the development of the probabilities that a task will be performed by a 3-level or a 5-level using the CODAP information. The CODAP information on the percent time spent on each task,

TABLE 4-1

Task Time Predictor Model Results

LCOM	5-Level Task Time	3-Level Task Time	LCOM	5-Level Task Time	3-Level Task Time
H71L02	.60	.88	T71T02	.10	-.01**
H71L03	.80	1.17	T71V00	.30	.07**
H71L04	1.60	2.33	T71V01	.10	-.22**
H71M01	.20	.23	T71V02	.20	-.08**
H71S00	1.80	2.40	T72300	.10	-.01**
H71T00	.10	.09**	T72301	.80	1.08
H72300	.70	1.02	T72302	.10	-.01**
H72301	1.00	1.46	T72303	.10	-.01**
H72500	1.20	1.97	T72500	1.20	1.87
M71L02	1.00	1.52	T72501	.20	.36
M71L03	.50	.79	T72502	.10	.21
M71M01	.20	.29	V71L06	.90	1.22
M71S00	1.00	1.30	V71L08	.30	.28**
M71S01	1.20	1.59	V71L09	.10	-.01**
M71T00	.50	.79	V71L10	.20	.14**
M71T02	.10	.14	V71L11	1.00	1.37
M71V0G	1.30	1.74	V71M03	.10	-.01**
M72300	.20	.29	V71M04	.10	-.01**
M72301	1.50	2.24	V71S00	.90	1.00
M72500	1.20	2.02	V71S01	.20	-.08**
R71L00	.40	.29**	V71S02	.10	-.22**
R71L06	.40	.29**	V71T00	.90	1.22
R71L07	1.20	1.52	V71T01	.10	-.01**
R71M02	.20	.00**	V71T02	.10	-.01**
R71S00	1.30	1.45	V72300	.20	.14**
R71T00	.30	.15**	V72301	.10	-.01**
R71V00	.50	.28**	V72302	.10	-.01**
R72300	1.30	1.66	V72303	1.00	1.37
R72301	.50	.50	V72500	1.40	2.17
R72302	.40	.29**	V72501	.20	.36
R72500	1.70	2.46	V72502	.10	.21
R72501	.50	.72	X71L00	.80	.94
T71L06	.75	1.00	X71L03	1.30	1.66
T71L08	.50	.64	X71L04	.10	-.15**
T71L09	.10	-.01**	X71L05	.80	.94
T71L10	.20	.14**	X71M03	.20	.00**
T71M04	.40	.43	X71S00	1.80	2.17
T71M05	.10	-.01**	X71T00	.30	.15**
T71M06	.10	-.01**	X71V00	1.10	1.16
T71S00	2.00	2.60	X72300	1.70	2.24
T71S01	.20	-.08**	X72301	1.00	1.23
T71S02	.10	-.22	X72302	1.00	1.23
T71T00	1.20	1.66	X72500	4.00	5.80
T71T01	.10	-.01**	END TASKS		

broken down by skill level group, was obtained from Dr. Henk Ruck, Human Resources Lab, Brooks AFB, Texas. This CODAP information was taken from the subgroup of navigation specialists working on all models of the F-4 aircraft in order to obtain a representative sample in the survey of 3-level F-4 navigation specialists. The 5-level group sample used in this research included both 5-levels and 7-levels in the survey. The results in Table 4-2 show only approximately 28% of the work represented in CODAP could be mapped to LCOM. The degree of mapping is probably lower than what would have been obtained from an all F-4E sample group since various other navigation systems on other F-4 models are registering work in the overall F-4 sample group which does not occur in the F-4E sample group. Since only a measure of the relative difference in the work done by the different skill groups is being sought, differences between the work represented in the F-4 and F-4E sample groups is assumed to have small significance. In fact, no matter which group of specialists are taken (all F-4 or just F-4E), not all of the CODAP tasks can be mapped to LCOM since CODAP includes administrative, management, and other such tasks which are not represented in the LCOM F-4E data base.

With the CODAP to LCOM mapping complete, a Fortran program was used to calculate the conditional probability of a 3-level or 5-level performing a given task over the different skill level mixtures required by the research

TABLE 4-2

CODAP to LCOM Mapping Results for
Percent Time Spent

F-4E Navigation System	LCOM Action Code	3-Level	5-Level	Combined Group Sample
71L00	H & T	1.3870	1.4261	1.4216
	M	2.2430	1.7685	1.8246
	R & X	3.4020	3.3699	3.3738
	V	3.0243	3.4499	3.3995
71M00	H & T	.9518	.7334	.7589
	M	.1932	.2259	.2221
	R & X	1.4900	1.6607	1.6407
	V	.7478	.7364	.7378
71S00 & 71V00	H & T	1.6555	1.5558	1.5677
	M	2.9753	2.1148	2.2164
	R & X	1.6410	1.8583	1.8325
	V	1.7502	2.2454	2.1869
71T00	H & T	1.6555	1.5558	1.5677
	M	1.1412	1.0290	1.0422
	R & X	.6460	.7902	.7732
	V	1.7502	2.2454	2.1869
72300	H & T	.7274	.6007	.6157
	M	.7652	.5344	.5616
	R & X	2.2750	1.[illegible]55	1.8256
	V	1.2751	.9[illegible]3[illegible]	1.0271
72500	H & T	.0555	.14[illegible]3	.1338
	M	.1373	.1305	.1313
	R & X	.0400	.[illegible]96	.3131
	V	.0136	.2888	.2562
TOTAL		28.5372	27.7720	27.8623

design. An example of the results is presented in Table 4-3. The first step in transforming the unmodified CODAP data on "percent time spent by group members," involved calculating a set of joint probabilities for each skill group and task as outlined in Chapter 3. As presented in Table 4-2 earlier, the CODAP to LCOM mapped data represents a table of conditional probabilities for a specific task group given a skill level group and the marginal probabilities for each task group are given as the percent time spent by both skill groups together. After transforming the data into a joint probability table and adding the probabilities across each task, a new set of marginal probabilities were calculated and compared to the original marginal probabilities. The differences between these marginal probabilities are shown along with the calculated marginal probabilities in the joint probability table in Table 4-3. After calculating all the joint probability tables, it was noted that for high skill level mixtures, the original marginal probabilities practically match the marginal probabilities obtained by adding the joint probabilities across each task. However, as the skill mixture decreases (the proportion of 3-levels increase), the difference between the calculated and original marginal probabilities becomes greater. Table 4-4 shows how the average difference in marginal probabilities varies with skill mixture. This effect can be partially attributed to differences in the number of significant digits between the 3-level

TABLE 4-3

Example of Joint Probability Table & Conditional Probability Table Obtained From the Probability Transformation Process Outlined in Chapter 3

PERSONNEL ASSIGNED 8 NUMBER OF THREE LEVELS 2 MIX= 4.5

JOINT PROBABILITY TABLE				CONDITIONAL PROBABILITY TABLE		
THREE	FIVE	MARGINAL	DIFF	THREE	FIVE	UNITY
.00346746	.01069604	.01416350	.00005263	.24481664	.75518336	1.00000000
.00560738	.01326392	.01887130	-.00062540	.29713818	.70286182	1.00000000
.00850500	.02527448	.03377948	-.00304157	.25178611	.74821389	1.00000000
.00756061	.02587399	.03343480	.00055994	.22613604	.77386396	1.00000000
.00237959	.00550040	.00787999	-.00029135	.30197904	.69802096	1.00000000
.00048290	.00169452	.00217742	.00004397	.22177515	.77822485	1.00000000
.00372500	.01245525	.01618025	.00022705	.23021894	.76978106	1.00000000
.00185959	.00552285	.00739244	-.00001422	.25290552	.74709448	1.00000000
.00413865	.01166882	.01580747	-.00013061	.26181615	.73818385	1.00000000
.00743817	.01586068	.02329884	-.00113464	.31925050	.68074950	1.00000000
.00410250	.01393725	.01803975	.00028525	.22741446	.77258554	1.00000000
.00437552	.01684016	.02121569	.00065331	.20624001	.79375999	1.00000000
.00413865	.01166882	.01580747	-.00013061	.26181615	.73818385	1.00000000
.00285298	.00771749	.01057047	-.00014823	.26990108	.73009892	1.00000000
.00161500	.00592650	.00754150	.00019850	.21414838	.78585162	1.00000000
.00437552	.01684016	.02121569	.00065331	.20624001	.79375999	1.00000000
.00181852	.00450537	.00632388	-.00016652	.28756329	.71243671	1.00000000
.00191291	.00400802	.00592093	-.00030484	.32307560	.67692440	1.00000000
.00568750	.01324155	.01892905	-.00067345	.30046410	.69953590	1.00000000
.00318766	.00745356	.01064122	-.00037044	.29955749	.70044251	1.00000000
.00013876	.00108205	.00122080	.00011691	.11365965	.88634035	1.00000000
.00034316	.00097870	.00132186	-.00000921	.25960488	.74039512	1.00000000
.00010100	.00262225	.00272226	.00040826	.03673415	.96326585	1.00000000
.00003392	.00216608	.00220000	.00036246	.01541627	.98458373	1.00000000
.25000000	.75000000	1.00000000	.00031645			
Group Marginal Probabilities		Unity	Calculated Average Absolute Difference			

TABLE 4-4

Skill Mixture Trends in the Difference of the Marginal Probability Predicted by CODAP and the Calculated Marginal Probabilities

Skill Mixture	Average Error Difference in Marginal Probabilities
3.0	.00211548
3.2	.00187561
3.25	.00181564
3.33	.00171569
3.40	.00163574
3.50	.00151580
3.60	.00139587
3.67	.00131591
3.75	.00121596
3.80	.00115600
4.0	.00091613
4.2	.00067625
4.25	.00061629
4.33	.00051634
4.4	.00043638
4.5	.00031645
4.6	.00019651
4.67	.00011656
4.75	.00001662
4.8	.00004336

and 5-level percent time data obtained from the Human Resources Lab. There is also a possibility that as the skill mixture decreases, the percent time spent by all members in both groups, is no longer representative for the work force characterized by that skill mixture. Overall, the average difference is less than 1% and is assumed to be insignificant. However, further research in this area is needed to substantiate this assumption and verify that the percent time spent by the different skill level groups and all groups together do not change significantly when the skill mixture composition of the work force changes.

Analysis of the Training Probability Quantification Procedures

The final area of methodology development involves determining the training probabilities. The information on the number of tasks and number of months it takes to qualify a 3-level in a specific task group area, as required in the training workload methodology outlined in Chapter 3, was developed through Delphi techniques. This information is shown in Table 4-5. Once formulated, this information was used in the equations developed in Chapter 3 to derive the training probabilities for each system-task group used in the CODAP to LCOM mapping procedure. An example of the training probability results is shown in Table 4-6. These results show that the probability of a task from a task group combination being used for training will increase as

TABLE 4-5

Delphi Results for Qualification Requirements for 3-Levels

Task Group Areas: NAV System	Task Group Areas: LCOM Action Code	Number of Months	Number of Tasks
71L00	H & T	18	18
	M	6	4
	R & X	2	3
	V	6	4
71M00	H & T	18	10
	M	6	3
	R & X	2	2
	V	6	3
7LS00 & 71V00	H & T	18	18
	M	6	4
	R & X	2	2
	V	6	4
71T00	H & T	18	10
	M	6	4
	R & X	2	1
	V	6	3
72300	H & T	18	10
	M	6	4
	R & X	2	3
	V	6	4
72500	H & T	18	10
	M	6	3
	R & X	2	1
	V	6	3

TABLE 4-6

Training Probabilities for the Verification Tasks for All Navigation Systems

System	Task Rqmts p/person for 60 day Simulation**	Expected Task Occurrences for 60 day Simulation*	Number of 3-Levels								
			1	2	3	4	5	6	7	8	9
71L00	1.3	41.67	.0312	.0624	.0936	.1248	.1560	.1872	.2184	.2496	.2808
71M00	1.0	1.5	.6667	.99	1.0	1.0	1.0	1.0	1.0	1.0	1.0
71S00 & 71V00	1.3	25.33	.0513	.1026	.1540	.2053	.2566	.3079	.3593	.4106	.4619
71T00	1.0	1.0	.99	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
72300	1.3	11.17	.1164	.2328	.3491	.4655	.5819	.6983	.8147	.9311	.999
72500	1.0	5.83	.1715	.3431	.5146	.6861	.8576	.99	1.0	1.0	1.0

** $\frac{\text{(Sim period)}}{\text{(\# months to qualify)}}$ (# Tasks to qualify)

* Data from preliminary simulations

the number of 3-levels in the workcenter increases. This is expected. Also, for certain system task groups, the frequency with which these tasks occur during the simulation is not enough to handle the prescribed training load for a large number of 3-levels in the workcenter. This is exhibited by the 100% probability for the task being used for training. This inability to handle the prescribed training load can have adverse impacts on the training which 3-levels receive in these tasks and can cause their training progression to move slower than desired.

Research Design Results

Upon completion of the procedures required by the three main areas in this LCOM methodology, the new mean task times, adjusted for the skill mixture relationship on task times, probability of the work being accomplished by a 3-level or 5-level, and training workload, were developed using a Fortran program. These new mean task times were for ed to the requirements of the LCOM task change card (TKCNG) and input into each corresponding simulation run required by the full factorial research design. The various dependent and independent variables used for the regression analysis were collected for each simulation. The regression data were categorized upon input to the regression analysis program by skill mixture, number of people, and simulation time period. Thus, six 10-day sets of statistics from the

main simulation level 1 report and post processor report were used to develop each category subfile of data based on skill mixture and number of people. This provided a total of 162 cases for each variable over 27 different skill mixture and manning combinations. An example of these statistics is shown in Table 4-7.

At this time, the regression analysis for each of the various dependent statistics listed in the Research Design section of Chapter 3 will be discussed. The SPSS computer outputs for each of these regression models can be found in Appendix E.

The regression relationship with the workcenter utilization rate (UTIL) as the dependent variable, Y, is:

$$Y = 119.799 + (-4.209)X_1 + (-2.9898)X_2 + (.2031)X_3 + (-.0961)X_4$$

The variable X_1 represents the total number of workers (PEOP) assigned to the workcenter, X_2 represents the skill mixture (MIX) of the workcenter work force and variables X_3 and X_4 are the blocking factors for workload, representing the total number of tasks (TASKS) accomplished in the workcenter and the total number of sorties (SORT) flown respectively. All of these independent variables together account for 82% of the variability in the utilization rate. The F-statistic value for each β coefficient is such to allow the conclusion

TABLE 4-7

Simulation Results for 8 Assigned Technicians and Skill Mixture of 4.5

Total Work Force	Skill Mixture	Simulation Per.	Number of Sorties	Sortie Rate	Flying Hours	Utilization Rate	Total Number Man-hours	Total Tasks	Total Back-ordered Tasks	Average Tasks in Backorder	Average Backorder Duration	Total Man-hours Backordered
8	4.500	1	763	1.05	1033.37	27.27	174.51	156	52	.25	1.15	118.84
8	4.500	2	763	1.05	1018.30	33.36	213.47	164	84	.43	1.23	207.35
8	4.500	3	777	1.08	1049.57	31.13	199.21	183	73	.25	.76	118.53
8	4.500	4	761	1.05	1022.79	29.74	190.30	180	82	.30	.87	138.23
8	4.500	5	760	1.05	1036.28	34.97	223.75	182	85	.40	1.11	182.37
8	4.500	6	754	1.05	1017.46	30.17	192.49	144	57	.28	1.17	132.99

that each β coefficient is significant and not equal to zero.[1] When isolating the skill mixture relationship with utilization rate by holding the other independent variables constant, the regression results show that for an increase in the skill mixture variable (increase the proportion of 5-levels in the work force), there is a corresponding decrease in utilization rate (measured in percentage points) by a factor of 2.9898.

The next regression model for total man-hours (MNHRS) used in the workcenter as the dependent variable, Y, is:

$$Y = 338.74 + (-17.199)X_2 + (1.255)X_3 + (-.259)X_4$$

The independent variables in this model are:

X_2 = MIX

X_3 = TASKS

X_4 = Flying hours (FLYHR)

Note that the variable for number of people did not enter in the regression model. This results from the F-statistic not being large enough to signify any impact on the regression model with the people variable entered into the model.

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[1]The F-statistic cited comes from the F-test procedures used in SPSS to determine the significance of each variable on the impact it has on the regression model. This test is similar to testing the null hypothesis that the β coefficient is equal to zero. For F-values greater than 5.Ø, the α significance level is less than .05. Therefore, for F-values greater than 5.Ø, the alternate hypothesis that β = Ø is acceptable at an α level of .05.

All of the other variables are significant though, and their combined effect accounts for 56% of the variability in total man-hours. When isolating the skill mixture effects on man-hours used, the regression model shows that for an increase in skill mixture there is a corresponding decrease in total man-hours used by a factor of 17.19 hours.

The regression analysis with the number of tasks backordered (BO) as the dependent variable, Y, gives the following regression model:

$$Y = 204.25 + (-10.50)X_1 + (-4.04)X_2 + (.796)X_3 + (-145.41)X_4$$

The independent variables in this model are:

X_1 = PEOP

X_2 = MIX

X_3 = TASKS

X_4 = Sortie Rate (RATE)

All of these variables show a significant impact on the model and, combined, they account for 86% of the variability associated with the number of tasks backordered. The direct relationship between skill mixture and the number of tasks backordered represented by the regression model shows that for an increase in skill mixture, the number of tasks backordered decreases by a factor of 4.04.

The next three regression models deal with various aspects of backorder statistics. Shown below are the

regression results for the average number of tasks in back-order status (AVEBO), average backorder duration (BODUR), and total man-hours backordered (MNHRBO), respectively.

AVEBO:

$$Y = 1.849 + (-.093)X_1 + (-.061)X_2 + (.0046)X_3 + (-.0016)X_4$$

BODUR:

$$Y = 2.30 + (-.124)X_1 + (-.107)X_2 + (.0016)X_3$$

MNHRBO:

$$Y = 319.40 + (-44.69)X_1 + (-28.92)X_2 + (2.09)X_3$$

The independent variables in these equations are:

X_1 = PEOP

X_2 = MIX

X_3 = TASKS

X_4 = SORT

As noted earlier, backorders are time related delays which can be viewed in different ways in order to measure the relationship of backorders to tasks or man-hours. The impact of skill mixture on the dependent variables after blocking for workload variability is significant in each case. Furthermore, the ability of each regression model to account for a significant portion of the variability associated with its dependent variable is also very good. The R SQUARE values indicate 66%, 41%, and 65%, respectively, for these regression models. The direct relationship between skill

mixture and each dependent variable shows for an incremental increase in skill mixture; the respective changes in each dependent variable are as follows: the average number of tasks in backorder decrease by a factor of .06 tasks, average backorder duration decreases by a factor of .107 hour, and total man-hours backordered decreases by a factor of 28.91 hours.

A final time dependent measure was calculated by taking the number of tasks accomplished and dividing by the total man-hours used. This productivity statistic (PROD) was used as the dependent variable in the following regression results:

$$Y = (-.522) + (.064)X_2 + (.0014)X_3$$

The independent variables are:

$$X_2 = \text{MIX}$$

$$X_3 = \text{SORT}$$

In order to avoid confounding the regression model with autocorrelation between the dependent and independent variables, only the number of sorties flown (SORT) was used as a blocking factor for workload variability. Skill mixture shows a significant impact on the regression model, and overall, the regression equation accounts for 23% of the variability in the productivity variable. The specific relationship shows an incremental increase in skill mixture

produces a corresponding increase in productivity by a factor of .06 tasks per man-hour.

The final regression model presented in this chapter is for the skill mixture variable as the dependent variable. This was done in order to determine if a regression model could be used to indicate the appropriate skill mixture for a given workload situation defined by independent variables such as utilization rate (UTIL), number of people (PEOP), number of tasks accomplished (TASKS), and number of sorties flown (SORT). The following regression model is the result of this analysis with MIX as the dependent variable:

$$Y = 12.13 + (-.308)X_1 + (-.073)X_2 + (.017)X_3 + (-.0077)X_4$$

where

X_1 = PEOP

X_2 = UTIL

X_3 = TASKS

X_4 = SORT

Using these four independent variables, 22% of the variability associated with skill mixture can be captured. The utilization rate variable has the strongest significance to the regression equation, followed by number of people, tasks accomplished, and finally number of sorties flown. The effect of the number of sorties flown in the regression equation is significantly less than the other independent

variables and, in fact, shows a 21% chance of being zero. For the remaining independent variables, their direct impact on skill mixture are as follows: an incremental increase in utilization rate corresponds to a decrease in skill mixture by a factor of .07; an incremental increase in number of people corresponds to a decrease in skill mixture by a factor of .30; and, finally, an incremental increase in number of tasks accomplished corresponds to an increase in skill mixture by a factor of .017.

Summary

The findings from the overall LCOM methodology presented in this chapter, have shown the feasibility and significance of using such an approach for explaining the impact of skill mixture on workcenter capability. The primary constraint throughout this methodology has been to reflect the structural model relationships conceptualized in Chapter 2 within the existing LCOM structure. The first step in this process involved establishing the task time relationship between 3-levels and 5-levels for the system/task groups worked by 328X1 navigation specialists. After deriving these task times, the probabilities of a 5-level or 3-level performing each task were determined using a CODAP to LCOM mapping scheme followed by a mathematical transformation of the conditional probabilities found in CODAP to those required by this research. The last step in preparing the LCOM data base was to incorporate the training probabilities for all

of the tasks performed by the 328X1 specialists and, finally, calculating the new mean task time for each task. With the modified data base established, a sensitivity analysis of skill mixture relationships was performed using the full factorial research design presented at the end of Chapter 3. The results of the final simulation regression analyses showed significant correlations between skill mixture and various measures of workcenter capability. In the next chapter, a summary of the major conclusions of this thesis and recommendations for further research will be discussed.

Chapter 5

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The objective of this thesis has been to develop and incorporate into LCOM a methodology which can be used to capture the skill mixture relationships within the workcenter, and distinguish the effects which skill mixture has on the productivity and output of the maintenance workcenter. The first step in reaching this objective was to establish a conceptual framework for understanding the complex relationships existing in the maintenance workcenter and overall maintenance system at large.

The conceptualized maintenance system presented in Chapter 2 provided an understanding of how to structure the relationships between the maintenance tasks, different skilled members of the work force, and decision structure used to assign these tasks to specifically skilled technicians in the work force. A formal structural model using Q-GERT networks was developed with the above relationships. In particular, the degree of experimental control which the modeler has over the simulation processes used in Q-GERT allowed for the development of a precise tool with which to structure the skill mixture problem. The Q-GERT model was able to distinguish changes in the status of the work force

at any given time in the workcenter's operation. The actual status of the work force was essential to the decision process used in assigning technicians to tasks based on their specific abilities and training requirements. In this manner, the particular skills of available technicians could be matched to the difficulty level of the next available task.

With the conceptualized model established, the next area of concern was to determine the effect of a technician's maintenance errors on the workload and workflow of the work-center. These errors are essentially due to mismatching the technician's skill ability with the difficulty of the task. The affects of such errors either increases the number of times the task is worked, or increases the failure rate of the particular aircraft system. Specific quantification of this relationship was not pursued, however, since such relationships are already partly reflected in the LCOM data base, and that any changes to these task proportions and failure rates could invalidate the model.

There were three major skill mixture relationships presented in the methodology which required quantification. First, was a quantification of the relationship between 3-level and 5-level task times and OJT task times. Based on a stratified sample of 5-level and 3-level task times for the various systems and tasks worked by the subject work-center, a regression analysis was performed and utilized as a predictor model for 3-level task times. Even though the

regression model variables were significant, the applicability of using this technique proved to be most effective in predicting task times for which the given 5-level task time was greater than 0.5 hours. Task times less than 0.5 hours were beyond the predictive capability of the regression model and indicated either a greater sample proportion was needed for data points within this time limit or perhaps the regression relationship below 0.5 hours is nonlinear. In order to quantify training task times, an assumption was made (based upon discussions with several maintenance technicians) that such training times would be equivalent to the 3-level task time for the particular task.

The second skill mixture relationship requiring quantification involved the OJT workload within the workcenter. Given the aircraft system and type of maintenance task, the probability that a task is performed in an OJT situation was determined by establishing a time table for task training progression, the required number of training situations per task, and the number of 3-levels requiring training. These training relationships were validated using Delphi techniques and were incorporated into the LCOM methodology. One deficiency noted with the procedure was that certain system/task groups studied in this thesis required 100% probability for training. This was due to the insufficient number of times these tasks occur (in an average LCOM simulation) with respect to the specified training workload.

The final skill mixture relationship requiring quantification concerned the probability that a specific maintenance task would be assigned and worked by a 5-level or 3-level technician. The method used to capture this relationship was derived from information in the Comprehensive Occupational Data Analysis Program on the subject workcenter AFSC (328X1). Since the CODAP data reflects the average percent time which the survey respondents spend on a wide variety of tasks, a CODAP to LCOM mapping scheme was developed to gather the task related information in CODAP which applied to LCOM tasks represented in the subject workcenter. The results of the task mapping scheme showed only 28% of the work represented in CODAP could be mapped to LCOM. This was expected since CODAP includes administrative, management, and other such tasks which are not represented in the LCOM data base. After the mapping scheme was complete, a mathematical transformation of the CODAP data was used to calculate the conditional probability of a 3-level or 5-level performing the task, given the specific task.

The methodology summarized above was intended to capture skill mixture relationships using simulation techniques and the Logistics Composite Model. The first step in determining the applicability of this methodology to LCOM required an understanding of the basic network structure within LCOM. Since LCOM does not distinguish between different skill level groups within the manpower resource a

restructuring of the basic networks to account for two separate manpower resources was proposed for each existing task. In order to capture the decision structure for assigning specifically skilled technicians to a given task with a specified difficulty, a resource substitution scheme was required. The substitution action would allow the simulation model to substitute a different skill level resource (in effect choose a different network path) for the primary resource, when the primary resource is not available. Resource substitution capability is an inherent aspect of LCOM software; however, the ability to transfer the resource's corresponding task time distribution is not. Thus, although the substitution procedure allowed a 3-level to substitute for a 5-level when necessary, it did not adjust the ability level of the 3-level resource with respect to task times. In order to alleviate this shortcoming in LCOM, major changes would be required in the LCOM software. Such changes were not pursued in this thesis. Instead, a framework was developed within the existing LCOM network structure which would approximate the decision structure discussed earlier. Basically, it involved calculating a weighted mean task time for a given task, based on the probability of the task being worked by a 3-level or 5-level. Since there were no structural changes to the LCOM networks, only the relevant task time changes for each task performed by the subject workcenter were required. This procedure was relatively simple

using the TKCNG task change card ability in LCOM and provided the necessary changes for representing skill mixture relationships.

After accomplishing all of the changes and procedures outlined above, the application of this LCOM methodology to distinguish the effects which skill mixture has on the productivity and output of the maintenance workcenter was investigated using a full factorial research design for skill mixture and number of people in the workcenter. The simulation results were collected and a regression analysis performed on various workcenter productivity and output statistics. Results of the regression analysis showed a consistent significant impact of skill mixture on the workcenter's capability. The analysis concentrated on the affects which skill mixture had (after blocking for workload variation) on the following: workcenter utilization rate, total maintenance man-hours used, total workorders backordered, average tasks in backorder, average backorder duration, total man-hours backordered, and as a measure for productivity, the number of tasks accomplished per man-hour. Specifically, the impact of increasing the skill mixture in the workcenter (increasing the ratio of 5-levels to 3-levels) showed the following results: a corresponding decrease in utilization rate by a factor of 2.9898, a decrease in the total man-hours used by a factor of 17.19 hours, a decrease in the number of tasks backordered by a factor of 4.04 backorders, a decrease

in the average number of tasks backordered by a factor of 0.06 tasks, a decrease in the average backorder duration by a factor of .107 hour, a decrease in the total man-hours backordered by a factor of 28.91 hours, and an increase in the productivity measure by a factor of .06 tasks per man-hour. Overall, the ability of the regression models to account for the variability associated with the workcenter's productivity and output statistics ranged from 23% to 86%. From these results, one may conclude that skill mixture affects provide a distinguishable impact on the productivity and output of the maintenance workcenter. Thus, the application of the LCOM methodology developed in this research may be a useful tool to manpower personnel using LCOM in the manpower determination process.

Recommendations for Further Research

There are several areas in this research topic which can be pursued further. First is predicting 3-level task times in those tasks which take less than 0.5 hours for a 5-level technician to perform. A regression predictor model, such as developed in this research, which covers the full spectrum of task times, would be beneficial for further use of this technique in predicting 3-level times for the LCOM methodology presented in this thesis.

Another, more complicated area for further research would be to test the sensitivity of CODAP survey techniques

to skill level mixture effects for individual survey groups with different skill mixtures. If the percent time spent by each skill level group on each task does not change but remains constant as the skill mixture of the group varies, then CODAP survey techniques are not sensitive to the skill mixture changes. Knowledge about this aspect of CODAP will further validate the methods used in this thesis to develop the 3-level and 5-level task probabilities. As a follow-on to this same area, further research to develop a survey tool, similar to the CODAP job inventory survey, which more accurately depicts the tasks as represented and used in the LCOM simulations, is needed. This will alleviate having to cross reference and map the CODAP information to the LCOM tasks. Also, as a corrollary to this, further research is needed to incorporate into LCOM many of the administrative and management tasks shown by CODAP as requiring manpower resources but not represented in LCOM. This source of manpower demand could have an affect on capabilities and manning requirements. An alternate or smaller sized simulation model may be appropriate for resolving the skill mixture problem and incorporating these administrative and management tasks discussed above. As such, further research can be applied towards expanding the Q-GERT framework presented in Chapter 2 of this report and developing a full structural model of all the management relationships and decision structures that occur in the workcenter, many of which were

not discussed here. The simulation model could then be used to answer many of the workcenter specific questions which LCOM does not model.

As a final recommendation for further research, a capability within the LCOM software should be developed which will adjust the task time distribution parameters when a substitution occurs. This will allow for the appropriate task time to be matched to the manpower resource assigned to the task. Such a capability not only has impacts on the skill mixture problem presented in this research but also on substitutions which currently occur in LCOM simulations of Production Oriented Maintenance Organizations. In these POMO simulations, a nonprimary technician may be assigned to perform a cross-utilization task. Since this kind of task is not the technician's primary area of responsibility, chances are it will take the technician longer to perform the task. If the task time substitution capability is incorporated into LCOM software, the methodology for modifying the networks directly and using the substitution scheme presented in Chapter 3 would be a feasible approach for analyzing skill mixture affects on the workcenter and would also be another area for further research.

In conclusion, this report has presented a basic framework for studying the skill mixture problem with LCOM. It has presented some clear-cut evidence that LCOM can resolve some of the skill level effects on the workcenter's

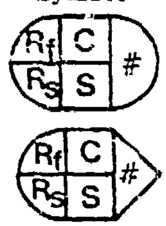
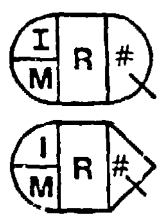
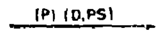
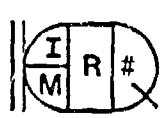
performance. With the added capability of adapting the LCOM software to allow for task time parameter modification upon resource substitution, it is promising that LCOM could be useful in determining appropriate skill mixtures for a given workcenter. If this is not possible, a smaller scale simulation model on the workcenter level can be used to address these same issues.

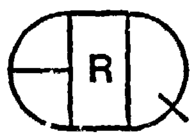
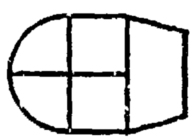
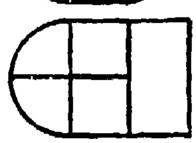
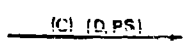
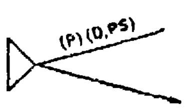
APPENDICES

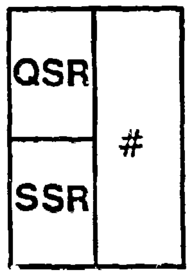
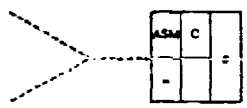
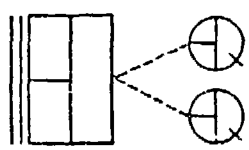
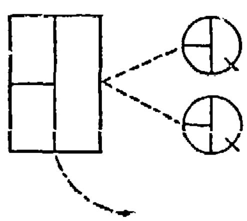
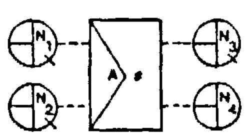
APPENDIX A

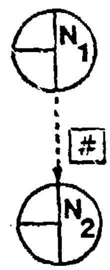
Q-GERT NETWORK SYMBOLS

This appendix was abstracted from Alan Pritsker's text, Modeling and Analysis Using Q-GERT Networks, 1979, and contains the descriptions of all the Q-GERT network symbology used in developing the structural model of the maintenance workcenter in Chapter 2.

Symbol	Definition
	R_f is the number of incoming transactions required to release the node for the first time. R_S is the number of incoming transactions required to release the node for all subsequent times. C is the criterion for holding the attribute set at a node. S is the statistics collection type or marking. # is the node number. D indicates deterministic branching from the node. ▷ indicates probabilistic branching from the node.
	I is the initial number of transactions at the Q-node. M is the maximum number of transactions permitted at the Q-node. R is the ranking procedure for ordering transactions at the Q-node. # is the Q-node number.
	Pointer to a source node or from a sink node.
(P) (D,PS)  [#] (N)	P is the probability of taking the activity (only used if probabilistic branching from the start node of the activity is specified). D is the distribution or function type from which the activity time is to be determined. PS is the parameter set number (or constant value) where the parameters for the activity time are specified. [#] is the activity number (N) is the number of parallel servers associated with the activity (only used if the start node of the activity is a Q-node).
	Routing of a transaction that balks from a Q-node. This symbol can not emanate from a regular node.
	Blocking indicator (only used with Q-nodes that can force preceding *service* activities to hold transactions because the Q-node is at its maximum capacity).

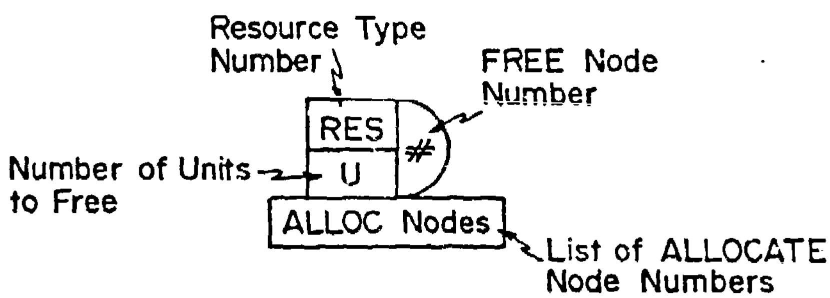
Symbol	Concept	Definition
	Value Assignment	A is the attribute number to which a value is to be assigned; if A+ is specified, add value to attribute A; if A– is specified, subtract value from attribute A. D is the distribution or function type from which assignment value is to be determined. PS is the parameter set number.
	Queue Ranking	R is the ranking procedure for ordering transactions at the Q-node. R can be specified as: F → FIFO; L → LIFO; B/i → Big value of attribute i. S/i → Small value of attribute i. If i= M, ranking is based on mark time.
	Conditional, Take-First Branching	 indicates conditional-take first branching from the node.
	Conditional, Take-all Branching	 indicates conditional-take all bra[illegible]ing from the node.
	Condition Specification for Branch	C is the condition specification for taking the activity (see Table 5-1).
	Attribute Based Probabilistic Branching	If P<1.0, P is the probability of taking the activity. If P≥1, P is an attribute number.

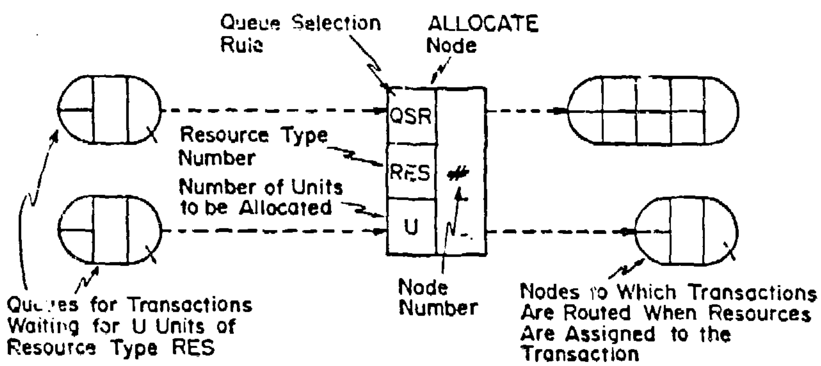
Symbol	Concept	Definition
	Selector node or S-node	QSR is the queue selection rule for routing transactions to or from Q-nodes (see Table 5-2). SSR is the server selection rule for decidi‑g which server to make busy if a choice exists (see Table 5-3). # is the S-node number.
--------------	Routing Indicator	Routing indicator for transaction flow to or from Q-nodes to S-nodes or Match nodes
	Assembly by S-nodes	ASM is the queue selection rule that requires transactions to be assembled from two or more queues.
	Blocking	Blocking at an S-node.
	Balking	Balking from an S-node.
	Match Node	# is the match node number. Transactions are routed from N_1 to N_3 and N_2 to N_4 when a match occurs. A is the attribute number on which the match is to be made

Symbol	Concept	Definition
	Nodal Modification	# is the activity number causing nodal modification. N_1 is the node number to be replaced when activity # is completed. N_2 is node number to be inserted when activity # is completed.

FREE NODES

The FREE node allows transactions to make resources available. At the FREE node, the resource type and the units of the resource to be freed are prescribed. Both of these quantities can be integer or attribute numbers. Thus, the resource number and the number of units to be freed can be carried as attributes of the transaction arriving to the FREE node. Branching from a FREE node can be DETERMINISTIC, PROBABILISTIC, or CONDITIONAL. The FREE node can have associated with it, a list of ALLOCATE nodes where the resources freed are to be reallocated. The symbol for the FREE node is shown below.





The ALLOCATE node resembles the S-node in shape and in the fact that transactions wait in Q-nodes that precede it. However, it differs from it graphically in two respects:

1) three spaces are available for information on the input side of the ALLOCATE node; and
2) dashed lines are used on both the input and output sides of the ALLOCATE node in the same fashion as the MATCH node.

An important observation is that Q-nodes preceding ALLOCATE nodes must reference ALLOCATE nodes in Field 10 and beyond in the same manner as S-nodes and MATCH nodes are referenced by preceding Q-nodes. On the input side of the ALLOCATE node, the following information is prescribed:

1) the queue selection rule (QSR) which can be any of those prescribed for an S-node except the ASM rule;
2) the resource number, RES, of the resource type to be allocated; and
3) the number of units, U, of RES to be allocated to each transaction at the ALLOCATE node.

Distribution and Function Types (See Table 2-1)		Parameter Values* (See Figure 3-2)			
Code	Key	1	2	3	4
AT	Attribute	-	-	-	-
BE	Beta	μ	a	b	σ
BP	Beta PERT	m	a	b	-
CO	Constant	μ	-	-	-
ER	Erlang	μ/k	a	b	k
EX	Exponential	μ	a	b	-
GA	Gamma	μ	a	b	σ
IN	Incremental	-	-	-	-
LO	Lognormal	μ	a	b	σ
NO	Normal	μ	a	b	σ
PO	Poisson	μ-a	a	b	-
TR	Triangular	m	a	b	-
UF	User Function	-	-	-	-
UN	Uniform	-	a	b	-

* $\longrightarrow$not used; $\mu \rightarrow$ mean; $\sigma \rightarrow$ standard deviation; m $\rightarrow$ mode; a $\rightarrow$ minimum or optimistic time; b $\rightarrow$ maximum or pessimistic time.

Branching Condition Codes (See Table 5-1)		Queue Selection Rules (See Table 5-2)		Server Selection Rules (See Table 5-3)	
Code	Key	Code	Key	Code	Key
T.R.V.	Time .R. Value	POR	Preferred order	POR	Preferred order
T.R.Ak	Time .R. Attribute k	CYC	Cyclic	CYC	Cyclic
Aj.R.V.	Attribute j.R. Value	RAN	Random	RAN	Random
Aj.R.Ak	Attribute j.R. Attribute k	LAV	Largest average number	LBT	Largest busy time
where R = {LT;LE;EQ;NE;GT; or GE}		SAV	Smallest average number	SBT	Smallest busy time
		LWF	Longest waiting of first	LIT	Longest idle time
Ni.R	Node i Released	SWF	Shortest waiting of first	SIT	Shortest idle time
Ni.N	Node i Not Released	LNQ	Largest number in queue	PFS	Probabilistic from free servers
NAj.R	Node Aj Released	SNQ	Smallest number in queue		
NAj.N	Node Aj Not Released	LNB	Largest number of balkers		
		SNB	Smallest number of balkers		
		LRC	Largest remaining capacity		
		SRC	Smallest remaining capacity		
		ASM	Assembly mode		

APPENDIX B

CODAP TASK CODE DEFINITIONS

This appendix was abstracted from the *Job Inventory for the Avionics Navigation Systems Career Ladder, AFSC 328X1, 32894 and 32900*, Report Number AFPT 90-328-379, dated January 1979. This appendix lists the CODAP task numbers and their description, which corresponds to the CODAP Data used in this report.

79. Inspect completed jobs

164. Adjust frequency modulation (FM) systems

165. Adjust ultra high frequency (UHF) receiver transmitters

166. Adjust very high frequency (VHF) systems

167. Perform on-equipment operational checks of FM systems

168. Perform on-equipment operational checks of interphone systems

169. Perform on-equipment operational checks of UHF systems

170. Perform on-equipment operational checks of VHF systems

171. Remove or install FM antennas

172. Remove or install FM control boxes

173. Remove or install FM receiver-transmitters

174. Remove or install interphone control boxes

175. Remove or install interphone cords

176. Remove or install UHF antennas

177. Remove or install UHF control boxes

178. Remove or install UHF mounts

179. Remove or install UHF receiver-transmitters

180. Remove or install VHF antennas

181. Remove or install VHF control boxes

182. Remove or install VHF receiver-transmitters

183. Troubleshoot FM antennas

184. Troubleshoot FM control boxes

185. Troubleshoot FM receiver-transmitters

186. Troubleshoot interphone control boxes

187. Troubleshoot UHF antenna systems

188. Troubleshoot UHF control boxes

189. Troubleshoot UHF receiver-transmitters

190. Troubleshoot VHF antennas

191. Troubleshoot VHF control boxes

192. Troubleshoot VHF receiver-transmitters

H. PERFORMING GENERAL AIRCRAFT NAVIGATIONAL SYSTEMS MAINTENANCE

222. Adjust navigational pressurization systems
223. Align navigational pressurization systems
224. Clean parts or components
225. Diagnose mock-up malfunctions
226. Diagnose test equipment malfunctions
227. Dust navigational equipment, aerospace ground equipment (AGE), or test equipment
228. Forward test equipment to precision measuring equipment laboratory (PMEL)
229. Inspect desiccants
230. Inspect navigational equipment for corrosion
231. Inspect parts received from supply or manufacturers
232. Inspect waveguides (other than in rendezvous radar beacon systems)
233. Locate maintenance information in technical publications or Air Force technical orders (TO)
234. Maintain physical security of AIMS components, data, or publications
235. Paint navigational equipment
236. Perform inprogress or critical step inspections
237. Perform operational checks of navigational pressurization systems
238. Perform TCTO modifications on bearing distance heading indicator (BDHI) equipment
239. Perform TCTO modifications on forward-looking radar, multi-mode, or terrain-following radar systems
240. Perform TCTO modifications on IFF/SIF/AIMS equipment
241. Perform TCTO modifications on long range navigation (LORAN) equipment
242. Perform TCTO modifications on navigation test equipment
243. Perform TCTO modifications on radio/radar altimeter equipment
244. Perform TCTO modifications on rendezvous radar beacon equipment
245. Perform TCTO modifications on search radar equipment

246. Perform TCTO modifications on station keeping equipment (SKE)
247. Perform TCTO modifications on tactical air navigation (TACAN) equipment
248. Perform TCTO modifications on very high frequency omni range (VOR) ILS equipment
249. Perform time compliance technical order (TCTO) modifications on automatic direction finder (ADF) equipment
250. Remove or replace aircraft inspection plates or panels
251. Remove or replace desiccants
252. Remove or replace multiple wire plugs
253. Remove or replace navigational pressurization system barometric switches
254. Remove or replace navigational pressurization system control boxes
255. Remove or replace navigational pressurization system lines
256. Remove or replace navigational pressurization system pumps
257. Remove or replace navigational pressurization system waveguides
258. Remove or replace navigational system relays
259. Remove or replace navigational system wiring or cables
260. Remove or replace radio frequency (RF) coaxial connectors
261. Safety wire or bond system components
262. Set up flightline maintenance stands
263. Test continuity of coaxial cables
264. Test or evaluate new or modified equipment
265. Trace circuits or signals using wiring diagrams or schematics
266. Treat navigational equipment for corrosion by using chemicals, scraping, or recoat with conformal coatings

J. MAINTAINING RENDEZVOUS RADAR BEACON SYSTEMS

ON-EQUIPMENT MAINTENANCE

331. Inspect rendezvous radar beacon waveguides for corrosion or moisture
332. Operate associated systems checking rendezvous radar beacons
333. Operationally check rendezvous radar beacon systems
334. Perform operational checks on rendezvous radar beacon using aircraft search and weather radar systems
335. Perform operational checks on rendezvous radar beacon using rendezvous radar beacon system flightline test equipment
336. **Remove or replace rendezvous radar beacon antennas**
337. **Remove or replace rendezvous radar beacon control units**
338. **Remove or replace rendezvous radar beacon cooling fans**
339. **Remove or replace rendezvous radar beacon equipment mounts**
340. **Remove or replace rendezvous radar beacon interface pulse amplifiers**
341. **Remove or replace rendezvous radar beacon receiver-transmitters**
342. **Remove or replace rendezvous radar beacon waveguide assemblies**
343. **Troubleshoot rendezvous radar beacon systems**

K. MAINTAINING RADIO/RADAR ALTIMETERS

ON-EQUIPMENT MAINTENANCE

361. Adjust radio/radar altimeter systems
362. Align radio/radar altimeter systems
363. Operate associated systems checking radio/radar altimeters
364. Perform operational check of radio/radar altimeter using BITE or self-tests
365. Perform operational checks of radio/radar altimeter using radio/radar altimeter flightline test equipment
366. Remove or replace radio altimeter cooling fans
367. Remove or replace radio/radar altimeter amplifiers
368. Remove or replace radio/radar altimeter antennas
369. Remove or replace radio/radar altimeter equipment mounts
370. Remove or replace radio/radar altimeter indicators
371. Remove or replace radio/radar altimeter power supplies
372. Remove or replace radio/radar altimeter receiver-transmitters
373. Troubleshoot radio/radar altimeter systems

L. MAINTAINING AIRBORNE IDENTIFICATION SYSTEMS
ON-EQUIPMENT MAINTENANCE
403. Key IFF/SIF/AIMS equipment
404. Operate associated systems checking IFF/SIF/AIMS systems
405. Operationally check IFF/SIF/AIMS systems
406. Perform operational checks of IFF/SIF/AIMS systems using BITE
407. Perform operational checks using IFF/SIF/AIMS flightline test equipment
408. Remove or replace IFF/SIF/AIMS antenna switching units
409. Remove or replace IFF/SIF/AIMS antennas
410. Remove or replace IFF/SIF/AIMS built-in test sets
411. Remove or replace IFF/SIF/AIMS control units
412. Remove or replace IFF/SIF/AIMS equipment mounts
413. Remove or replace IFF/SIF/AIMS interrogators
414. Remove or replace IFF/SIF/AIMS KIT computers
415. Remove or replace IFF/SIF/AIMS receiver-transmitters
416. Set IFF/SIF/AIMS codings
417. Troubleshoot IFF/SIF/AIMS systems

M. MAINTAINING TACTICAL AIR NAVIGATION (TACAN) SYSTEMS AND ASSOCIATED INSTRUMENTATION EQUIPMENT

ON-EQUIPMENT MAINTENANCE

492. Adjust TACAN system line replaceable units (LRU)

493. Align TACAN system LRU

494. Operate associated systems checking BDHI

495. Operate associated systems checking TACAN systems

496. Operationally check BDHI indicators

497. **Operationally check BDHI selector panels**

498. **Operationally check navigation selector panels**

499. **Operationally check TACAN systems using ground stations**

500. **Perform operational checks of TACAN systems using TACAN flightline test equipment**

501. **Perform operational checks of TACAN systems using TACAN BITE**

502. **Remove or replace BDHI indicators**

503. **Remove or replace BDHI selector panels**

504. **Remove or replace navigation selector panels**

505. **Remove or replace TACAN antenna selector switches**

506. **Remove or replace TACAN antenna selectors**

507. **Remove or replace TACAN antennas**

508. **Remove or replace TACAN control units**

509. **Remove or replace TACAN equipment mounts**

510. **Remove or replace TACAN indicators**

511. **Remove or replace TACAN instrumentation couplers**

512. **Remove or replace TACAN mount airflow filters**

513. Remove or replace TACAN mount power relays

514. Remove or replace TACAN phase comparators

515. Remove or replace TACAN receiver-transmitters

516. Troubleshoot BDHI systems

517. Troubleshoot navigation selector panel systems

518. Troubleshoot TACAN systems

APPENDIX C

F-4E OPERATIONAL SCENARIO

This appendix was abstracted from the LCOM Manpower Standards Final Report for the F-4E model used in this study. Changes were annotated where applicable to represent the scenario used in this thesis. The F-4E model used was a peacetime-CONUS version structured for a production-oriented maintenance organization.

Purpose

The parameters as outlined herein will be used for guidance and input during LCOM simulation of F-4E maintenance activities in a peacetime environment. These parameters will aid in designing work flow processes and sortie scheduling.

Organization

The wing structure will be as outlined in AFR 66-5 and will include a Deputy Commander for Maintenance Staff agency and three maintenance squadrons.

Operations

1. Mission Types: (identified)

    a. A-G = Air-to-Ground
    b. A-A = Air-to-Air
    c. MAV = MAVERICK
    d. DART = Target Tow
    e. FCF = Functional Check Flight
    f. ALRT = ALERT - Air-to-Air

2. Mission Scheduling Factors: (See Table C-1)

TABLE C-1

Mission Scheduling Factors

(1) Mission Type:	A-G	A-A	MAV	DART	FCF	ALRT
(2) Mission Priority:	2	2	2	2	3	1
(3) Percent Total Sorties:	56	33.2	8	1.3	0.7	0.8
(4) Flight Size (Min/Max):	2/4	2/4	2/4	1/1	1/1	1/2
(5) Mean Sortie Length (Hr) (Avg 1.33):	1.11±.22	1.73±.17	1.07±.08	1.43±.20	.83±.3	1.33±.4
(6) Proportion Day/Night:	80/20	75/25	100/0	100/0	100/0	50/50
(7) Delay before Cancellation (Hr):	2.0	2.0	2.0	2.0	2.0	N/A
(8) Air Abort Rate:	1%	1%	1%	3%	1%	1%
(9) Gun: (639 rds 20MM)	1	1	1	1	1	1
(10) Chaff/Flares:	No/Yes	Yes/No	No/No	No/No	No/No	No/No

TABLE C-1 (continued)

(1) Mission Type:	A-G	A-A	MAV	DART	FCF	ALRT
(11) Probability of:						
(a) Firing Gun:	100%	3%	0	0	0	0.1%
(b) Expending Munitions:	100%	0	0	0	0	0.1%
(c) Expending Chaff/ Flares:	0/20%	3%/0	0	0	0	0

3. Scheduling Policy:

a. Weather Data: Weather effects are not accounted for in these simulations.

b. Spare Policy: Spare aircraft will be prepared for the first of each mission type each day.

c. Day/Night mission definition:

(1) Day: 0600 - 1800

(2) Night: 1800 - 0600

d. Ground Alert

(1) Two (2) aircraft per wing will be dedicated to 10 minute alert, 24 hrs/day, 7 days/week.

(2) Launch three (3) two (2) ship missions per week, replenish in 2.0 hours after launch.

e. Sortie Rate: The monthly utilization rate will be a minimum of 21 sorties/acft/month. Sortie length will vary by mission type.(se

f. Quick Turn Procedures: Combat quick turn will not be used.

Maintenance

1. Cross-utilization will not be used. Shop dispatch will not be modeled.

2. Preflight, Thru Flight, Post Flight and LOX servicing will be accomplished in accordance with T.O. 00-20-5 and T.O. 1F-4C-6 requirements.

3. Aircraft refueling will be single point from a refueling truck or refueling pit. This will be accomplished within 30 minutes after aircraft has landed unless precluded by unscheduled maintenance.

4. Avionic equipment code setting will be accomplished prior to the first sortie of the day.

5. Line Replaceable Unit (LRU) remove and replace maintenance will be used to accomplish on-equipment work.

6. Supply will be unconstrained.

7. Scheduled Maintenance:

a. Phase inspection will be a 600 hour inspection cycle with six (6) 100 hour inspections.

(1) Hour inspections 100, 200, 400, and 500 will be minor and able to be accomplished on the flight line.

(2) Hour inspections 300 and 600 are major and will require the aircraft to be towed into the inspection dock.

b. A calendar Postflight inspection will be accomplished every seven (7) days.

APPENDIX D

RESULTS OF THE 3-LEVEL TASK TIME
QUANTIFICATION PROCEDURE

This appendix contains the data used in the task time regression procedure from SPSS in order to develop the 3-level task time predictor model; and, the SPSS computer output of the final regression results. Data points 1 through 20 are from the surveys conducted by TAC/XPM and data points 21 through 39 were abstracted from the data used by Howell in his doctoral dissertation. Refer to Chapter 4 for the analysis of the results.

TABLE D-1

3-Level and 5-Level Task Times

i	71M X_1	71S X_2	71T X_3	723 X_4	725 X_5	H X_6	M X_7	R/X X_8	T X_9	5-level time X_{10}	3-level time Y_i
1	0	0	0	0	0	0	0	1	0	.5	.67
2	0	0	0	0	0	0	1	0	0	.17	.25
3	0	0	0	0	0	0	0	0	0	.5	.5
4	0	0	0	0	0	0	0	0	0	.75	.92
5	0	0	0	0	0	1	0	0	0	.75	.92
6	1	0	0	0	0	0	0	1	0	.5	.5
7	1	0	0	0	0	0	1	0	0	.25	.25
8	0	1	0	0	0	0	0	0	1	1.25	1.50
9	0	1	0	0	0	0	0	0	0	.75	.75
10	0	1	0	0	0	1	0	0	0	1.25	1.50
11	0	1	0	0	0	0	0	1	0	1.17	1.17
12	0	1	0	0	0	0	1	0	0	.5	.5
13	0	1	0	0	0	0	0	1	0	1.33	1.50
14	0	1	0	0	0	0	1	0	0	.5	.67
15	0	0	0	1	0	0	0	0	1	.25	.33
16	0	0	0	1	0	0	0	0	0	.17	.25
17	0	0	0	1	0	1	0	0	0	.25	.25
18	0	0	0	1	0	0	0	1	0	1.00	1.25

TABLE D-1 (continued)

i	71M X_1	71S X_2	71T X_3	723 X_4	725 X_5	H X_6	M X_7	R/X X_8	T X_9	5-level time X_{10}	3-level time Y_i
19	0	0	0	1	0	0	0	1	0	.75	.75
20	0	0	0	1	0	0	1	0	0	.25	.25
21	0	0	0	0	0	1	0	0	0	1.00	2.00
22	0	0	0	0	0	0	1	0	0	.5	.8
23	0	0	0	0	0	0	1	0	0	.5	.8
24	0	0	0	0	0	0	1	0	0	.5	.8
25	0	0	0	0	0	0	1	0	0	.5	.8
26	0	0	0	0	0	0	1	0	0	2.8	4.2
27	0	0	0	0	0	0	1	0	0	.5	.8
28	0	0	0	0	0	0	1	0	0	.5	.8
29	1	0	0	0	0	0	1	0	0	1.6	2.4
30	1	0	0	0	0	0	1	0	0	1.00	1.5
31	1	0	0	0	0	0	1	0	0	.7	1.1
32	0	1	0	0	0	0	1	0	0	1.2	1.8
33	0	0	1	0	0	0	1	0	0	.3	1.2
34	0	0	0	1	0	1	0	0	0	1.00	2.00
35	0	0	0	1	0	0	1	0	0	1.8	2.7
36	0	0	0	1	0	0	1	0	0	1.0	1.5
37	0	0	0	1	0	0	1	0	0	.5	.8

TABLE D-1 (continued)

i	71M X_1	71S X_2	71T X_3	723 X_4	725 X_5	H X_6	M X_7	R/X X_8	T X_9	5-level time X_{10}	3-level time Y_i
38	0	0	0	0	1	1	0	0	0	.7	1.4
39	0	0	0	0	1	0	1	0	0	1.5	2.3

TASK TIME REGRESSION   04/27/81   11.49.39.

FILE NONAME (CREATION DATE = 04/27/81)

* M U L T I P L E   R E G R E S S I O N *

DEPENDENT VARIABLE.. Y1

VARIABLE(S) ENTERED ON STEP NUMBER 7.. X11

MULTIPLE R	.99434	ANALYSIS OF VARIANCE	DF	SUM OF SQUARES	MEAN SQUARE	F	SIGNIFICANCE
R SQUARE	.98870	REGRESSION	7.	23.80724	3.28675	338.07495	0
ADJUSTED R SQUARE	.98588	RESIDUAL	28.	.27221	.00972		
STD DEVIATION	.09859	COEFF OF VARIABILITY	3.0 PCT				

------------------- VARIABLES IN THE EQUATION -------------------

VARIABLE	B	STD ERROR B	F / SIGNIFICANCE	BETA / ELASTICITY
X10	1.4532147	.35598375E-01	1674.9350 .000	.9655852 1.05558
X2	-.21611478	.43611784E-01	24.556294 .000	-.1117303 -.34361
X8	-.13909941	.59289449E-01	5.5042131 .026	-.0644550 -.12115
X5	.21765399	.81094674E-01	7.2035839 .012	.0519988 .11153
X7	.14949586	.47884547E-01	9.7469235 .004	.0916530 .17956
X6	.92307550E-01	.74723870E-01	1.5260042 .227	.0317261 .10702
X11	-.64258627E-01	.53739410E-01	1.4298059 .242	-.0297804 -.00977
(CONSTANT)	-.87091838E-01	.54466258E-01	2.5568181 .121	

---------- VARIABLES NOT IN THE EQUATION ----------

VARIABLE	PARTIAL	TOLERANCE	F / SIGNIFICANCE
X1	-.09219	.89999	.23145234 .634
X3	-.04948	.96254	.66278397E-01 .799
X4	.02941	.68838	.23375216E-01 .880
X9	.03456	.53733	.32278583E-01 .859
SQ	.23139	.06259	1.5274618 .227

APPENDIX E

REGRESSION RESULTS ON THE WORKCENTER PERFORMANCE INDICATORS

This appendix contains the SPSS computer output for each of the regression models of the workcenter performance indicators as presented in the Research Design section of Chapter 3. Refer to Chapter 4 for analysis of these regression models.

FINAL ANALYSIS 05/13/81 13.55.45. PAGE 6

FILE NONAME (CREATION DATE = 05/13/81)

SUBFILE									
SIXA	SIXB	SIXC	SIXD	SIXE	SIXF	SIXG	EIGA	EIGB	EIGC
EIGD	EIGE	EIGF	EIGG	EIGH	EIGI	TENA	TENB	TENC	TEND
TENE	TENF	TENG	TENH	TENI	TENJ	TENK			

* M U L T I P L E R E G R E S S I O N *

DEPENDENT VARIABLE.. UTIL UTILIZATION RATE

VARIABLE(S) ENTERED ON STEP NUMBER 4.. SORT NUMBER OF SORTIES FLOWN

MULTIPLE R	.85572
R SQUARE	.82'13
ADJUSTED R SQUARE	.81573
STD DEVIATION	3.7.213

ANALYSIS OF VARIANCE	DF	SUM OF SQUARES	MEAN SQUARE	F	SIGNIFICANCE
REGRESSION	4.	9823.76679	2457.17526	179.26732	....
RESIDUAL	157.	2152.60284	13.71136		
COEFF OF VARIABILITY	11.2 PCT				

-------------------- VARIABLES IN THE EQUATION --------------------

VARIABLE	B	STD ERROR B	F / SIGNIFICANCE	BETA / ELASTICITY
PEOP	-.[illegible]	.[illegible]	53.[illegible]1553	-.[illegible] / -1.[illegible]
TASKS	.2 3 [illegible]263	.1[illegible]E-01	132.[illegible]	.[illegible] / 1.[illegible]
MIX	-2.[illegible]	.[illegible]	43.[illegible]	-.[illegible] / -.[illegible]
SORT	-.[illegible]	.[illegible]E-01	5.325120[illegible] / .[illegible]	-.[illegible]33.92 / -2.21167
(CONSTANT)	[illegible]	[illegible]	16.[illegible] / .000	

------------ VARIABLES NOT IN THE EQUATION ------------

VARIABLE	PARTIAL	TOLERANCE	F / SIGNIFICANCE

ALL VARIABLES ARE IN THE EQUATION.

FINAL ANALYSIS 05/13/81 13.55.49. PAGE 19

FILE NONAME (CREATION DATE = 05/13/81)

SUBFILE									
SIXA	SIX9	SIXC	SIXD	SIXE	SIXF	SIX3	E1JA	E2GB	E2GC
E1GC	E1GE	E1GF	E1GG	E2G4	E1GI	TEN1	TE1B	TENC	TEND
TENE	TENF	TENG	TENH	TENI	TENJ	TENK			

* M U L T I P L E R E G R E S S I O N *

DEPENDENT VARIABLE.. MHRS TOTAL MANHOURS USED

VARIABLE(S) ENTERED ON STEP NUMBER 3.. FLYHR FLYING HOURS FLOWN

MULTIPLE R	.7[illegible]	ANALYSIS OF VARIANCE	DF	SUM OF SQUARES	MEAN SQUARE	F	SIGNIFICANCE
R SQUARE	.5[illegible]	REGRESSION	3.	66753.01616	23321.2[illegible]	67.17[illegible]	.
ADJUSTED R SQUARE	.5[illegible]	RESIDUAL	133.	[illegible].65/87	[illegible]		
STD DEVIATION	2[illegible]	COEFF OF VARIABILITY	9.[illegible]				

--------------------- VARIABLES IN THE EQUATION ---------------------

VARIABLE	B	STD ERROR B	F / SIGNIFICANCE	BETA / ELASTICITY
TASKS	[illegible]1743	.9[illegible]-01	162.51213 / .000	.6739.45 / .03[illegible]3
MIX	-17.[illegible]3	2.[illegible]	46.191395 / .0[illegible]	-.33[illegible]5 / -.32[illegible]
FLYHR	-.2[illegible]2	.1757517[illegible]	[illegible].64[illegible] / .0[illegible]	-.1[illegible]7 25 / -[illegible]79
(CONSTANT)	33[illegible]	1[illegible]6.[illegible]2	5.5[illegible] / .[illegible]17	

---------- VARIABLES NOT IN THE EQUATION ----------

VARIABLE	PARTIAL	TOLERANCE	F / SIGNIFICANCE
PEOP	.0[illegible]5	.96[illegible]3	.[illegible] / .[illegible]

FINAL ANALYSIS 05/13/81 13.55.43. PAGE 29

```
FILE     NONAME   (CREATION DATE = 05/13/81 )
SUBFILE  SIXA     SIX9     SIXC     SIXD     SIXE     SIXF     SIXG     EIGA     EIGB     EIGC
         EIGD     EIGE     EIGF     EIGG     EIGH     EIGI     TENA     TENB     TENC     TEND
         TENE     TENF     TENG     TENH     TENI     TENJ     TENK.
```

* M U L T I P L E   R E G R E S S I O N *

DEPENDENT VARIABLE.. B) NUMBER OF TASKS BACKORDERED

VARIABLE(S) ENTERED ON STEP NUMBER ... RATE SORTIE RATE

MULTIPLE R	.92579	ANALYSIS OF VARIANCE	DF	SUM OF SQUARES	MEAN SQUARE	F	SIGNIFICANCE
R SQUARE	.85710	REGRESSION	4.	7,311.42511	1857.85628	244.9665.	..
ADJUSTED R SQUARE	.85339	RESIDUAL	157.	1,380.67382	75.83072		
STD DEVIATION	8.7.854	COEFF OF VARIABILITY	11.1 PCT				

------------------ VARIABLES IN THE EQUATION ------------------

VARIABLE	B	STD ERROR B	F SIGNIFICANCE	BETA ELASTICITY
PEOP	-10.693080	.42735314	603.52567 0	-.7303161 -1.13066
TASKS	.73513917	.41333112E-01	369.97833 0	.5725 56 1.57616
MIX	-4.2613747	1.1627436	14.401635 .000	-.1135363 -.26.74
RATE	-145.41381	64.092766	5.147463. .025	-.0675536 -1.35174
(CONSTANT)	214.24754	57.555077	9.1327533 .003	

------------ VARIABLES NOT IN THE EQUATION ------------

VARIABLE	PARTIAL	TOLERANCE	F SIGNIFICANCE

ALL VARIABLES ARE IN THE EQUATION.

FINAL ANALYSIS 05/13/81 13.50.49. PAGE 38

FILE NONAME (CREATION DATE = 05/13/81)

SUBFILE	SIXA	SIXB	SIXC	SIXD	SIXE	SIXF	SIXG	EIGA	EIGB	EIGC
	EIGD	EIGE	EIGF	EIGG	EIGH	EIGI	TENA	TENB	TENC	TEND
	TENE	TENF	TENG	TENH	TENI	TENJ	TENK			

* M U L T I P L E R E G R E S S I O N *

DEPENDENT VARIABLE.. AVERD AVE NUMBER OF TASKS IN 30

VARIABLE(S) ENTERED ON STEP NUMBER 4.. SORT NUMBER OF SORTIES FLOWN

MULTIPLE R	.81237	ANALYSIS OF VARIANCE	DF	SUM OF SQUARES	MEAN SQUARE	F	SIGNIFICANCE
R SQUARE	.65994	REGRESSION	4.	4.75387	1.15647	75.34.42	....
ADJUSTED R SQUARE	.65173	RESIDUAL	157.	2.44418	.01557		
STD DEVIATION	.12477	COEFF OF VARIABILITY	32.7 PCT				

-------------------- VARIABLES IN THE EQUATION --------------------

VARIABLE	B	STD ERROR B	F / SIGNIFICANCE	BETA / ELASTICITY
PEOP	-.93015191E-01	.61955210E-02	220.11559	-.7.55290
				-2..2 69
TASKS	.45570750E-02	.59304.70E-03	59.2032.2	.3595540
			0	1.97009
MIX	-.60.7503533E-01	.15213510E-01	15.930230	-.1855.20
			.00	-.53124
SORT	-.10531.1E-02	.133.63138E-02	1.4195450	-...... 24
			.230	-3.15290
(CONSTANT)	1..45= E-	1. 050526	3.359757	
			.059	

---------- VARIABLES NOT IN THE EQUATION ----------

VARIABLE	PARTIAL	TOLERANCE	F / SIGNIFICANCE

ALL VARIABLES ARE IN THE EQUATION.

FINAL ANALYSIS [illegible]/13/81 13.[illegible].[illegible]. PAGE 46

FILE NONAME (CREATION DATE = [illegible]/13/81)
SUBFILE SIXA SIXB SIXC SIXD SIXE SIXF SIXG EIGA EIGB EIGC
EIGD EIGE EIGF EIGG EIGH EIGI TENA TENB TENC TEND
TENE TENF TENG TENH TENI TENJ TENK..

* M U L T I P L E   R E G R E S S I O N *

DEPENDENT VARIABLE.. 90DUR AVE 90 DURATION

VARIABLE(S) ENTERED ON STEP NUMBER 3.. TASKS NUMBER OF TASKS ACCOMPLISHED

MULTIPLE R	.6[illegible]2[illegible]	ANALYSIS OF VARIANCE	DF.	SUM OF SQUARES	MEAN SQUARE	F	SIGNIFICANCE
R SQUARE	.[illegible]131[illegible]	REGRESSION	3.	[illegible].27.72	2.42451	3[illegible].[illegible]6972	
ADJUSTED R SQUARE	.[illegible].1[illegible]5	RESIDUAL	133.	1[illegible].33[illegible]63	.055[illegible]1		
STD DEVIATION	.2[illegible]3[illegible]5	COEFF OF VARIABILITY	23.1 PCT				

-------------------- VARIABLES IN THE EQUATION --------------------

VARIABLE	B	STD ERROR B	F / SIGNIFICANCE	BETA / ELASTICITY
PEOP	-.[illegible]243[illegible]67[illegible]	.1251457[illegible]E-01	98.76215[illegible] / .0[illegible]	-.6[illegible]57[illegible]8 / -.333[illegible]6
MIX	-.1.[illegible]34[illegible]3	.3125[illegible]E-01	11.731[illegible] / .0[illegible]	-.2631[illegible]23 / -.33[illegible]5
TASKS	.[illegible]7[illegible]E-02	.121[illegible]723E-02	1.66645[illegible] / .155	.0792[illegible]3 / .23[illegible]7[illegible]
(CONSTANT)	2.[illegible]	.2[illegible]2.0[illegible]	83.92242[illegible] / [illegible]	

---------- VARIABLES NOT IN THE EQUATION ----------

VARIABLE	PARTIAL	TOLERANCE	F / SIGNIFICANCE

ALL VARIABLES ARE IN THE EQUATION.

FINAL ANALYSIS 05/13/81 13.56.49. PAGE 54

FILE NONAME (CREATION DATE = 05/13/81)
SUBFILE SIXA SIXB SIXC SIXD SIXE SIXF SIXG EIGA EIGB EIGC
EIGD EIGE EIGF EIGG EIGH EIGI TENA TENB TENC TEND
TENE TENF TENG TENH TENI TENJ TENK

* M U L T I P L E R E G R E S S I O N *

DEPENDENT VARIABLE.. MNHRBO TOTAL MNHRS BACKORDERED

VARIABLE(S) ENTERED ON STEP NUMBER 3.. MIX SKILL LEVEL MIXTURE

MULTIPLE R	.83751	ANALYSIS OF VARIANCE	DF	SUM OF SQUARES	MEAN SQUARE	F	SIGNIFICANCE
R SQUARE	.69215	REGRESSION	3.	1061256.11359	353752.03703	96.70561	
ADJUSTED R SQUARE	.68587	RESIDUAL	153.	560240.50342	3663.8.132		
STD DEVIATION	59.35935	COEFF OF VARIABILITY	33.4 PCT				

------------------- VARIABLES IN THE EQUATION -------------------

VARIABLE	B	STD ERROR B	F / SIGNIFICANCE	BETA / ELASTICITY
PECF	-44.53.114	2.3252.19	232.76775	-.7153182
			.000	-2.15051
TASKS	2.1932.4	.2530354	54.373159	.3455246
			.000	1.33219
MIX	-26.916171	7.3013529	13.584031	-.1951024
			.000	-.64542
(CONSTANT)	315.4.337	59.556216	29.309625	
			.000	

---------- VARIABLES NOT IN THE EQUATION ----------

VARIABLE	PARTIAL	TOLERANCE	F / SIGNIFICANCE

ALL VARIABLES ARE IN THE EQUATION.

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FINAL ANALYSIS                                                                        05/14/81     11.40.51.     PAGE  2.5

FILE    NONAME    (CREATION DATE =  05/14/81 )
SUBFILE   SIXA        SIXB        SIXC        SIXD        SIXE        SIXF        SIXG          EIGA        EIGB        EIGC
          EIGD        EIGE        EIGF        EIGG        EIGH        EIGI        TENA          TENB        TENC        TEND
          TENE        TENF        TENG        TENH        TENI        TENJ        TENK

* * * * * * * * * * * * * * * * * * * * * * * *  M U L T I P L E   R E G R E S S I O N  * * * * * * * * * * * * * * * * * * * * * * *

DEPENDENT VARIABLE..    PROD

VARIABLE(S) ENTERED ON STEP NUMBER   2..    SORT        NUMBER OF SORTIES FLOWN

MULTIPLE R              .48537         ANALYSIS OF VARIANCE     DF       SUM OF SQUARES        MEAN SQUARE             F      SIGNIFICANCE
R SQUARE                .23724         REGRESSION                2.             .29339            .14669          24.70662          .000
ADJUSTED R SQUARE       .22745         RESIDUAL                159.             .94431            .00594
STD DEVIATION           .07707         COEFF OF VARIABILITY      9.7 PCT

-------------------- VARIABLES IN THE EQUATION ---------------------          ---------- VARIABLES NOT IN THE EQUATION -----------

VARIABLE            B           STD ERROR B         F           BETA             VARIABLE      PARTIAL     TOLERANCE          F
                                               ------------  ----------                                                  ------------
                                               SIGNIFICANCE  ELASTICITY                                                  SIGNIFICANCE

MIX          .64067652E-01   .93837774E-02   46.614627      .4723155
                                                     0        .32278
SORT         .13883516E-02   .91260916E-03   2.3256792      .1154259
                                                  .089       1.33562
(CONSTANT)  -.52239173       .52658043        .73709488
                                                  .402

ALL VARIABLES ARE IN THE EQUATION.
```

FINAL ANALYSIS 05/15/81 12.32.10. PAGE 74

FILE NONAME (CREATION DATE = 05/15/81)
SUBFILE SIXA SIXB SIXC SIXD SIXE SIXF SIXG EIGA EIGB EIGC
EIGD EIGE EIGF EIGG EIGH EIGI TENA TENB TENC TEND
TENE TENF TENG TENH TENI TENJ TENK..

* M U L T I P L E   R E G R E S S I O N *

DEPENDENT VARIABLE.. MIX SKILL LEVEL MIXTURE

VARIABLE(S) ENTERED ON STEP NUMBER 4.. SOR NUMBER OF SORTIES FLOWN

		ANALYSIS OF VARIANCE	DF	SUM OF SQUARES	MEAN SQUARE	F	SIGNIFICANCE
MULTIPLE R	.46339	REGRESSION	4.	14.69055	3.72465	11.12776	.000
R SQUARE	.22059	RESIDUAL	157.	52.55051	.33472		
ADJUSTED R SQUARE	.20104	COEFF OF VARIABILITY	14.5 PCT				
STD DEVIATION	.57855						

------------------- VARIABLES IN THE EQUATION ------------------- ---------- VARIABLES NOT IN THE EQUATION ----------

VARIABLE	B	STD ERROR B	F / SIGNIFICANCE	BETA / ELASTICITY	VARIABLE	PARTIAL	TOLERANCE	F / SIGNIFICANCE
UTIL	-.7293605.7E-01	.11325758E-01	41.522136 0	-.9727535 -.61529	BC	-.03593	.13244	.2.221262 .654
PEOP	-.3176891-	.5447376E5-01	31.934324 0	-.7657673 -.67437				
TASKS	.16592594E-01	.34977245E-02	22.504937 .000	.4263023 .88616				
SORT	-.7736327E6-02	.62591576E-02	1.5293556 .218	-.394039 -1.47630				
(CONSTANT)	12.130518	4.2135231	6.3535604 .013					

APPENDIX F

RESULTS OF THE WORK PROBABILITY QUANTIFICATION PROCEDURE

This appendix provides the complete results of the work probability quantification procedure for each skill mixture combination required by the research design presented at the end of Chapter 3. This procedure involved transforming the conditional probability table obtained from the CODAP to LCOM mapping scheme to a joint probability table, and then transforming the joint probability table to the conditional probability table giving the probability that a given task will be performed by a 3-level or 5-level. The exact procedures for these probability table transformations are given in Chapter 3. Refer to Chapter 4 for the analysis of this procedure.

PERSONNEL ASSIGNED 5 NUMBER OF THREE LEVELS 6 MIX= 3.

JOINT PROBABILITY TABLE

THREE	FIVE	MARGINAL	DIFF
.01386984	0.00000000	.01386984	.00134629
.02242953	0.00000000	.02242953	-.00418372
.03402000	0.00000000	.03402000	-.00028210
.03024326	0.00000000	.03024326	.00375148
.00951836	0.00000000	.00951836	-.00192972
.00193159	0.00000000	.00193159	.00028980
.01490000	0.00000000	.01490000	.00150730
.00747836	0.00000000	.00747836	-.00010014
.01655461	0.00000000	.01655461	-.00087775
.02975267	0.00000000	.02975267	-.00758847
.01641000	0.00000000	.01541000	.00191500
.01750210	0.00000000	.01750210	.00436690
.01655461	0.00000000	.01655461	-.00087775
.01141193	0.00000000	.01141193	-.00098969
.00646000	0.00000000	.00646000	.00127200
.01750210	0.00000000	.01750210	.00436690
.00727407	0.00000000	.00727407	-.00111671
.00765164	0.00000000	.00765164	-.00203554
.02275000	0.00000000	.02275000	-.00449440
.01275063	0.00000000	.01275063	-.00247985
.00055502	0.00000000	.00055502	.00078268
.00137265	0.00000000	.00137265	-.00305999
.00040000	0.00000000	.00040000	.00273052
.00013566	0.00000000	.00013566	.00242680
1.00000000	0.00000000	1.00000000	.00211548

CONDITIONAL PROBABILITY TABLE

THREE	FIVE	UNITY
1.00000000	0.00000000	1.00000000
1.00000000	0.00000000	1.00000000
1.00000000	0.00000000	1.00000000
1.00000000	0.00000000	1.00000000
1.00000000	0.00000000	1.00000000
1.00000000	0.00000000	1.00000000
1.00000000	0.00000000	1.00000000
1.00000000	0.00000000	1.00000000
1.00000000	0.00000000	1.00000000
1.00000000	0.00000000	1.00000000
1.00000000	0.00000000	1.00000000
1.00000000	0.00000000	1.00000000
1.00000000	0.00000000	1.00000000
1.00000000	0.00000000	1.00000000
1.00000000	0.00000000	1.00000000
1.00000000	0.00000000	1.00000000
1.00000000	0.00000000	1.00000000
1.00000000	0.00000000	1.00000000
1.00000000	0.00000000	1.00000000
1.00000000	0.00000000	1.00000000
1.00000000	0.00000000	1.00000000
1.00000000	0.00000000	1.00000000
1.00000000	0.00000000	1.00000000
1.00000000	0.00000000	1.00000000

PERSONNEL ASSIGNED 5 NUMBER OF THREE LEVELS 5 MIX= 3.333333333333

JOINT PROBABILITY TABLE				CONDITIONAL PROBABILITY TABLE		
THREE	FIVE	MARGINAL	DIFF	THREE	FIVE	UNITY
.01155820	.00237690	.01393510	.00023103	.82943068	.17056912	1.00000000
.01869128	.00294754	.02163882	-.00333300	.86378474	.13621526	1.00000000
.02835000	.00561655	.03396655	-.00022865	.83454467	.16535533	1.00000000
.02520271	.00574978	.03095249	.00304225	.81423867	.18576133	1.00000000
.00793197	.00122231	.00915428	-.00156564	.86647664	.13352336	1.00000000
.00160966	.00037655	.00198622	.00023517	.81041343	.18958657	1.00000000
.01241567	.00276783	.01518450	.00122280	.81771982	.18228018	1.00000000
.00623196	.00122730	.00745926	-.00008104	.83546629	.16453371	1.00000000
.01379551	.00259307	.01638858	-.00071172	.84177568	.15822432	1.00000000
.02479389	.00352459	.02831849	-.00615428	.87553732	.12446268	1.00000000
.01367500	.00309717	.01677217	.00155283	.81533890	.18466110	1.00000000
.01458508	.00374226	.01832734	.00354166	.79581002	.20418998	1.00000000
.01379551	.00259307	.01638858	-.00071172	.84177568	.15822432	1.00000000
.00950994	.00171500	.01122494	-.00080270	.84721538	.15278462	1.00000000
.00538333	.00131700	.00670033	.00103167	.80344261	.19655739	1.00000000
.01458508	.00374226	.01832734	.00354166	.79581002	.20418998	1.00000000
.00606172	.00100119	.00706292	-.00090555	.85824654	.14175346	1.00000000
.00637635	.00089057	.00726703	-.00165034	.87743668	.12256332	1.00000000
.01895833	.00294257	.02190090	-.00364530	.86564175	.13435825	1.00000000
.01062553	.00165635	.01228187	-.00201109	.86513885	.13486115	1.00000000
.00046252	.00024045	.00070297	.00063473	.65734677	.34265323	1.00000000
.00114387	.00021749	.00136136	-.00004871	.84024162	.15975838	1.00000000
.00033333	.00058273	.00091606	.00221446	.35387785	.63612215	1.00000000
.00011305	.00048135	.00059440	.00196805	.19019474	.80980526	1.00000000
.83333333	.16666667	1.00000000	.00171569			

PERSONNEL ASSIGNED 5 NUMBER OF THREE LEVELS 4 MIX= 3.566566656667

JOINT PROBABILITY TABLE

THREE	FIVE	MARGINAL	DIFF
.00924656	.00475380	.01400036	.00021577
.01495302	.00589587	.02084810	-.00260228
.02268000	.01123310	.03391310	-.00017520
.02016217	.01149955	.03166172	.00233302
.00634558	.00244462	.00879020	-.00120156
.00128772	.00075312	.00204084	.00018055
.00993333	.00553567	.01546900	.00093830
.00498557	.00245460	.00744017	-.00006195
.01103641	.00518614	.01622255	-.00054569
.01983511	.00704919	.02688430	-.00472010
.01094000	.00619433	.01713433	.00119067
.01166806	.00748452	.01915258	.00271642
.01103641	.00518614	.01622255	-.00054569
.00760795	.00343000	.01103795	-.00061571
.00430667	.00263400	.00694067	.00079133
.01166806	.00748452	.01915256	.00271642
.00484936	.00200239	.00685175	-.00069440
.00510109	.00178134	.00688243	-.00126634
.01516667	.00588513	.02105180	-.00279620
.00850042	.00331270	.01181312	-.00154233
.00037002	.00048091	.00085093	.00048678
.00091510	.00043498	.00135007	-.00003742
.00026667	.00116545	.00143212	.00169840
.00009044	.00096270	.00105314	.00150931
.66666667	.33333333	1.00000000	.00131591

CONDITIONAL PROBABILITY TABLE

THREE	FIVE	UNITY
.66045184	.33954816	1.00000000
.71723683	.28276317	1.00000000
.66876812	.33123188	1.00000000
.63679957	.36320043	1.00000000
.72189239	.27810761	1.00000000
.63097644	.36902356	1.00000000
.64214450	.35785550	1.00000000
.67008815	.32991185	1.00000000
.68031267	.31968733	1.00000000
.73779534	.26220466	1.00000000
.63848414	.36151586	1.00000000
.60921624	.39078376	1.00000000
.68031267	.31968733	1.00000000
.68925421	.31074579	1.00000000
.62049755	.37950245	1.00000000
.60921624	.39078376	1.00000000
.70775621	.29224379	1.00000000
.74117531	.25882469	1.00000000
.72044512	.27955488	1.00000000
.71957481	.28042519	1.00000000
.43483943	.56516057	1.00000000
.67781233	.32218767	1.00000000
.18620457	.81379543	1.00000000
.08587803	.91412197	1.00000000

PERSONNEL ASSIGNED 5 NUMBER OF THREE LEVELS 3 MIX= 4.

JOINT PROBABILITY TABLE

THREE	FIVE	MARGINAL	DIFF
.00693492	.00713069	.01406562	.00015052
.01121477	.00884261	.02005738	-.00181156
.01701000	.01684955	.03385965	-.00012175
.01512163	.01724933	.03237095	.00161379
.00475918	.00366693	.00842611	-.00083747
.00096579	.00112968	.00209547	.00012592
.00745000	.00830350	.01575350	.00065380
.00373918	.00368190	.00742108	-.00004286
.00827730	.00777921	.01605652	-.00037966
.01487533	.01057378	.02545012	-.00323592
.00820500	.00929150	.01749550	.00082850
.00875105	.01122678	.01997782	.00189117
.00827730	.00777921	.01605652	-.00037366
.00570597	.00514499	.01085096	-.00042872
.00323000	.00395100	.00718100	.00059100
.00875105	.01122678	.01997782	.00189117
.00363703	.00300358	.00664061	-.00048325
.00382582	.00267202	.00649783	-.00088174
.01137500	.00882770	.02020270	-.00194710
.00637532	.00496904	.01134436	-.00107357
.00027751	.00072136	.00099887	.00033805
.00068632	.00065247	.00133879	-.00002614
.00020000	.00174818	.00194818	.00118235
.00006783	.00144405	.00151189	.00105057
.50000000	.50000000	1.00000000	.00091623

CONDITIONAL PROBABILITY TABLE

THREE	FIVE	UNITY
.49304076	.50695924	1.00000000
.55913426	.44086574	1.00000000
.50236786	.49763214	1.00000000
.46713569	.53286431	1.00000000
.56481346	.43518654	1.00000000
.46089524	.53910476	1.00000000
.47291078	.52708922	1.00000000
.50385907	.49614093	1.00000000
.51551050	.48448950	1.00000000
.58452909	.41547091	1.00000000
.46895093	.53104907	1.00000000
.43803808	.56196192	1.00000000
.51551050	.48448950	1.00000000
.52584888	.47415112	1.00000000
.44979808	.55020192	1.00000000
.43803808	.56196192	1.00000000
.54769558	.45230442	1.00000000
.58878359	.41121641	1.00000000
.56304355	.43695645	1.00000000
.56198114	.43801886	1.00000000
.27782416	.72217584	1.00000000
.51264457	.48735543	1.00000000
.10266018	.89733982	1.00000000
.04486549	.95513451	1.00000000

PERSONNEL ASSIGNED 5 NUMBER OF THREE LEVELS 2 MIX= 4.3333333333333

JOINT PROBABILITY TABLE

THREE	FIVE	MARGINAL	DIFF
.00462326	.00950759	.01413087	.00008526
.00747651	.01179015	.01926666	-.00102084
.01134000	.02246620	.03380620	-.00006830
.01008109	.02299910	.03308019	.00091455
.00317279	.00488924	.00806203	-.00047339
.00064386	.00150624	.00215010	.00007129
.00496667	.01107133	.01603800	.00036930
.00249279	.00490920	.00740199	-.00002377
.00551820	.01037229	.01589049	-.00021363
.00991756	.01409838	.02401593	-.00185173
.00547000	.01238857	.01785867	.00046633
.00583403	.01496904	.02080307	.00106593
.00551820	.01037229	.01589049	-.00021363
.00380398	.00685999	.01066397	-.00024173
.00215333	.00526800	.00742133	.00031067
.00583403	.01496904	.02080307	.00106593
.00242469	.00400477	.00642946	-.00027210
.00255055	.00356269	.00611323	-.00049714
.00758333	.01177027	.01935360	-.00109800
.00425021	.00662539	.01087560	-.00060482
.00018501	.00096182	.00114683	.00019088
.00045755	.00086995	.00132750	-.00001485
.00013333	.00233090	.00246423	.00066629
.00004522	.00192541	.00197063	.00059183
.33333333	.66666657	1.00000000	.00051634

CONDITIONAL PROBABILITY TABLE

THREE	FIVE	UNITY
.32717591	.67282409	1.00000000
.38805438	.61194562	1.00000000
.33544143	.66455857	1.00000000
.30474693	.69525307	1.00000000
.39354707	.60645293	1.00000000
.29945670	.70054330	1.00000000
.30968117	.69031883	1.00000000
.33677247	.66322753	1.00000000
.34726450	.65273550	1.00000000
.41295733	.58704267	1.00000000
.30629386	.69370614	1.00000000
.28044094	.71955906	1.00000000
.34725450	.65273550	1.00000000
.35671301	.64328699	1.00000000
.29015451	.70984549	1.00000000
.28044094	.71955906	1.00000000
.37712175	.62287825	1.00000000
.41721708	.58278292	1.00000000
.39183063	.60816937	1.00000000
.39080235	.60919765	1.00000000
.16132160	.83867840	1.00000000
.34466850	.65533150	1.00000000
.05410743	.94589257	1.00000000
.02294752	.97705248	1.00000000

PERSONNEL ASSIGNED 5 NUMBER OF THREE LEVELS 1 MIX= 4.66666666667

JOINT PROBABILITY TABLE

THREE	FIVE	MARGINAL	DIFF
.00231164	.01188449	.01419613	.00002000
.00373826	.01473768	.01847594	-.00023012
.00567000	.02808275	.03375275	-.00001485
.00504054	.02874888	.03378942	.00020532
.00158539	.00611155	.00769795	-.00010931
.00032193	.00168280	.00220473	.00001666
.00248333	.01383917	.01532250	.00008480
.00124639	.00613650	.00738289	-.00000467
.00275910	.01296536	.01572446	-.00004760
.00495878	.01762297	.02258175	-.00041755
.00273500	.01548583	.01822083	.00010417
.00291702	.01871129	.02162831	.00024069
.00275910	.01296535	.01572446	-.00004760
.00190199	.00857499	.01047698	-.00005474
.00107567	.00658500	.00766167	.00007033
.00291702	.01871129	.02162831	.00024069
.00121234	.00500596	.00521831	-.00006895
.00127527	.00445336	.00572863	-.00011254
.00379167	.01471283	.01850450	-.00024890
.00212511	.00828174	.01040584	-.00013606
.00009250	.00120227	.00129478	.00004293
.00022877	.00108744	.00131622	-.00000357
.00006567	.00291363	.00298029	.00015023
.00002261	.00240675	.00242937	.00013309
.16666667	.83333333	1.00000000	.00011656

CONDITIONAL PROBABILITY TABLE

THREE	FIVE	UNITY
.16283597	.83716403	1.00000000
.20233101	.79766899	1.00000000
.16798631	.83201369	1.00000000
.14917518	.85082482	1.00000000
.20608018	.79391982	1.00000000
.14601839	.85398161	1.00000000
.15214173	.84785827	1.00000000
.16882169	.83117831	1.00000000
.17546558	.82453442	1.00000000
.21959228	.78040772	1.00000000
.15010290	.84989710	1.00000000
.13487026	.86512974	1.00000000
.17546558	.82453442	1.00000000
.18153976	.81846024	1.00000000
.14052643	.85947357	1.00000000
.13487026	.86512974	1.00000000
.19436374	.80503626	1.00000000
.22261380	.77738620	1.00000000
.20490511	.79509489	1.00000000
.20420267	.79579733	1.00000000
.07144391	.92855609	1.00000000
.17381189	.82618811	1.00000000
.02236918	.97763082	1.00000000
.00930715	.99069285	1.00000000

PERSONNEL ASSIGNED 8 NUMBER OF THREE LEVELS 8 MIX= 3.

JOINT PROBABILITY TABLE

THREE	FIVE	MARGINAL	DIFF
.01386984	0.00000000	.01386984	.00034629
.02242353	0.00000000	.02242353	-.00418372
.03402000	0.00000000	.03402000	-.00028210
.03024326	0.00000000	.03024326	.00375148
.00951836	0.00000000	.00951836	-.00192972
.00193159	0.00000000	.00193159	.00028980
.01490000	0.00000000	.01490000	.00150730
.00747836	0.00000000	.00747836	-.00010014
.01655461	0.00000000	.01655461	-.00087775
.02975267	0.00000000	.02975267	-.00758847
.01641000	0.00000000	.01641000	.00191500
.01750210	0.00000000	.01750210	.00436690
.01655461	0.00000000	.01655461	-.00087775
.01141193	0.00000000	.01141193	-.00098969
.00646000	0.00000000	.00646000	.00127200
.01750210	0.00000000	.01750210	.00436690
.00727407	0.00000000	.00727407	-.00111671
.00765164	0.00000000	.00765164	-.00203554
.02275000	0.00000000	.02275000	-.00449440
.01275063	0.00000000	.01275063	-.00247985
.00055502	0.00000000	.00055502	.00078268
.00137265	0.00000000	.00137265	-.00005999
.00040000	0.00000000	.00040000	.00273052
.00013566	0.00000000	.00013566	.00242680
1.00000000	0.00000000	1.00000000	.00211546

CONDITIONAL PROBABILITY TABLE

THREE	FIVE	UNITY
1.00000000	0.00000000	1.00000000
1.00000000	0.00000000	1.00000000
1.00000000	0.00000000	1.00000000
1.00000000	0.00000000	1.00000000
1.00000000	0.00000000	1.00000000
1.00000000	0.00000000	1.00000000
1.00000000	0.00000000	1.00000000
1.00000000	0.00000000	1.00000000
1.00000000	0.00000000	1.00000000
1.00000000	0.00000000	1.00000000
1.00000000	0.00000000	1.00000000
1.00000000	0.00000000	1.00000000
1.00000000	0.00000000	1.00000000
1.00000000	0.00000000	1.00000000
1.00000000	0.00000000	1.00000000
1.00000000	0.00000000	1.00000000
1.00000000	0.00000000	1.00000000
1.00000000	0.00000000	1.00000000
1.00000000	0.00000000	1.00000000
1.00000000	0.00000000	1.00000000
1.00000000	0.00000000	1.00000000
1.00000000	0.00000000	1.00000000
1.00000000	0.00000000	1.00000000
1.00000000	0.00000000	1.00000000

PERSONNEL ASSIGNED 5 NUMBER OF THREE LEVELS 7 MIX= 3.25

JOINT PROBABILITY TABLE

THREE	FIVE	MARGINAL	DIFF
.01213511	.00178257	.01391879	.00029735
.01962584	.00221065	.02183649	-.00359058
.02976750	.00421241	.03397991	-.00024201
.02646285	.00431233	.03077518	.00321956
.00832857	.00091673	.00924530	-.00165665
.00169014	.00028242	.00197256	.00024883
.01303750	.00207588	.01511338	.00129393
.00654356	.00092048	.00746404	-.00008582
.01448528	.00194480	.01643009	-.00075322
.02603359	.00264345	.02867703	-.04651283
.01435875	.00232288	.01668163	.00164338
.01531433	.00280669	.01812103	.00374797
.01448528	.00194480	.01643009	-.00075322
.00998544	.00128625	.01127169	-.00084944
.00565250	.00098775	.00664025	.00109175
.01531433	.00280669	.01812103	.00374797
.00636481	.00075089	.00711570	-.00095824
.00669518	.00066800	.00736318	-.00174709
.01990625	.00220693	.02211318	-.00385758
.01115580	.00124225	.01239805	-.00212828
.00048555	.00018034	.00066589	.00057172
.00120106	.00016312	.00136418	-.00005153
.00035000	.00043704	.00078704	.00234348
.00011871	.00036101	.00047972	.00208274
.87500000	.12500000	1.00000000	.00181564

CONDITIONAL PROBABILITY TABLE

THREE	FIVE	UNITY
.87182322	.12817678	1.00000000
.89875339	.10124661	1.00000000
.87613227	.12386773	1.00000000
.85987632	.14012368	1.00000000
.90084339	.09915661	1.00000000
.85682561	.14317439	1.00000000
.86264610	.13735390	1.00000000
.87667863	.12332137	1.00000000
.88163155	.11836845	1.00000000
.90782010	.09217990	1.00000000
.86075247	.13924753	1.00000000
.84511396	.15488604	1.00000000
.88163155	.11836845	1.00000000
.88588677	.11411323	1.00000000
.85124807	.14875193	1.00000000
.84511396	.15488604	1.00000000
.89447361	.10552639	1.00000000
.90327785	.09672215	1.00000000
.90019864	.09980136	1.00000000
.89981011	.10018989	1.00000000
.72921232	.27078768	1.00000000
.88042903	.11957097	1.00000000
.44470209	.55529791	1.00000000
.24744736	.75255264	1.00000000

PERSONNEL ASSIGNED 8 NUMBER OF THREE LEVELS 6 MIX= 3.5

JOINT PROBABILITY TABLE				CONDITIONAL PROBABILITY TABLE		
THREE	FIVE	MARGINAL	DIFF	THREE	FIVE	UNITY
.01040238	.00356535	.01396773	.00024640	.74474399	.25525601	1.00000000
.01682215	.00442131	.02124346	-.00299764	.79187448	.20812552	1.00000000
.02551550	.00842433	.03393983	-.00020192	.75177170	.24822830	1.00000000
.02268244	.00862466	.03130711	.00268754	.72451420	.27548580	1.00000000
.00713877	.00183347	.00897224	-.00138360	.79565128	.20434872	1.00000000
.00144869	.00056484	.00201353	.00020766	.71947787	.28052213	1.00000000
.01117700	.00415175	.01532875	.00108055	.72911739	.27088261	1.00000000
.00560877	.00184095	.00744972	-.00007150	.75288318	.24711682	1.00000000
.01241596	.00388961	.01630556	-.00062870	.76145520	.23854480	1.00000000
.02231450	.00528689	.02760139	-.00543719	.80845562	.19154438	1.00000000
.01230750	.00464575	.01695325	.00137175	.72595700	.27403300	1.00000000
.01312657	.00561339	.01873996	.00312904	.70045890	.29954110	1.00000000
.01241596	.00388961	.01630556	-.00062870	.76145520	.23854480	1.00000000
.00855895	.00257250	.01113144	-.00070920	.76889817	.23110183	1.00000000
.00484500	.00197550	.00682050	.00091150	.71035848	.28964152	1.00000000
.01312657	.00561339	.01873996	.00312904	.70045890	.29954110	1.00000000
.00545555	.00150179	.00695734	-.00079995	.78414320	.21585680	1.00000000
.00573873	.00133601	.00707473	-.00145864	.81115787	.18884213	1.00000000
.01706250	.00441385	.02147635	-.00322075	.79447858	.20552142	1.00000000
.00956297	.00248452	.01204749	-.00177671	.79377277	.20622723	1.00000000
.00041627	.00036068	.00077695	.00056076	.53577179	.46422821	1.00000000
.00102948	.00032623	.00135572	-.00004307	.75936501	.24063499	1.00000000
.00030000	.00087409	.00117409	.00195643	.25551758	.74448242	1.00000000
.00010175	.00072203	.00082377	.00173868	.12351349	.87648651	1.00000000
.75000000	.25000080	1.00000000	.00151580			

PERSONNEL ASSIGNED 5 NUMBER OF THREE LEVELS 5 MIX= 3.75

JOINT PROBABILITY TABLE

THREE	FIVE	MARGINAL	DIFF
.00866865	.00534802	.01401667	.00019346
.01401846	.00663196	.02065042	-.00240463
.02126250	.01263724	.03389974	-.00016184
.01890204	.01293699	.03183903	.00215571
.00594898	.00275020	.00869918	-.00111054
.00120724	.00084726	.00205450	.00016689
.00931250	.00622763	.01554013	.00036717
.00467397	.00276143	.00743540	-.00005718
.01034663	.00583441	.01518104	-.00050418
.01859542	.00793034	.02652576	-.00436155
.01[illegible]256	.00596853	.01722488	.00110113
.01[illegible]	.00842008	.01935889	.00251610
.010[illegible]	.00583441	.01518104	-.00050418
.0072[illegible]	.00385875	.01099120	-.00056896
.00403[illegible]	.00296325	.00700075	.00073125
.01093881	.00842008	.01935889	.00251610
.00454529	.00225258	.00579898	-.00064161
.00478227	.00200401	.00678528	-.00117019
.01421875	.00662078	.02083953	-.00258393
.00796914	.00372678	.01169593	-.00142514
.00034689	.00054102	.00088791	.00044980
.00085790	.00048935	.00134725	-.00003460
.00025000	.00131113	.00156113	.00156939
.00008479	.00108304	.00116783	.00139463
.62500000	.37500000	1.00000000	.00121596

CONDITIONAL PROBABILITY TABLE

THREE	FIVE	UNITY
.61845[illegible]	.38154707	1.00000000
.67884629	.32115371	1.00000000
.62721725	.37278275	1.00000000
.59367497	.40632503	1.00000000
.68385531	.31614469	1.00000000
.58760818	.41239182	1.00000000
.59925515	.40074485	1.00000000
.62851092	.37138938	1.00000000
.63942919	.36057081	1.00000000
.70103254	.29896746	1.00000000
.59543248	.40456752	1.00000000
.56505350	.43494650	1.00000000
.63942919	.36057081	1.00000000
.64892412	.35107588	1.00000000
.57672392	.42327608	1.00000000
.56505350	.43494650	1.00000000
.66867310	.33132690	1.00000000
.70469673	.29530327	1.00000000
.68229722	.31770278	1.00000000
.68136067	.31863933	1.00000000
.39068004	.60931996	1.00000000
.63677981	.36322019	1.00000000
.16014028	.83985972	1.00000000
.07260421	.92739579	1.00000000

PERSONNEL ASSIGNED 8 NUMBER OF THREE LEVELS 4 MIX= 4.

JOINT PROBABILITY TABLE

THREE	FIVE	MARGINAL	DIFF
.00693492	.00713069	.01406562	.00015052
.01121477	.00884261	.02005738	-.00181156
.01701000	.01684965	.03385965	-.00012175
.01512163	.01724933	.03237095	.00162379
.00475918	.00366593	.00842511	-.00063747
.00096579	.00112968	.00209547	.00012592
.00745000	.00830355	.01575355	.00065330
.00373918	.00368190	.00742108	-.00004286
.00827730	.00777921	.01605652	-.00037966
.01487533	.01057378	.02545012	-.00328592
.00820500	.00929150	.01749650	.00082850
.00875105	.01122678	.01997782	.00189117
.00827730	.00777921	.01605552	-.00037966
.00570597	.00514499	.01085096	-.00042872
.00323000	.00395100	.00718100	.00055100
.00875105	.01122678	.01997782	.00189117
.00363703	.00300358	.00664061	-.00048325
.00382582	.00267202	.00649783	-.00088174
.01137500	.00882770	.02020270	-.00194710
.00637532	.00496904	.01134436	-.00107357
.00027751	.00072136	.00099888	.00033883
.00068532	.00065247	.00133879	-.00002614
.00020000	.00174818	.00194818	.00118235
.00006783	.00144485	.00151189	.00105057
.30000000	.50000000	1.00000000	.00091613

CONDITIONAL PROBABILITY TABLE

THREE	FIVE	UNITY
.49304078	.50695924	1.00000000
.55913426	.44086574	1.00000000
.50236786	.49763214	1.00000000
.46713569	.53286431	1.00000000
.56481346	.43518654	1.00000000
.46089524	.53910476	1.00000000
.47291078	.52708922	1.00000000
.50385907	.49614093	1.00000000
.51551050	.48448950	1.00000000
.58452909	.41547091	1.00000000
.46895093	.53104907	1.00000000
.43803808	.56196192	1.00000000
.51551050	.48448950	1.00000000
.52584888	.47415112	1.00000000
.44979808	.55020192	1.00000000
.43803808	.56196192	1.00000000
.54769558	.45230442	1.00000000
.58878359	.41121641	1.00000000
.56304355	.43695645	1.00000000
.56198114	.43801886	1.00000000
.27782416	.72217584	1.00000000
.51264457	.48735543	1.00000000
.10266018	.89733982	1.00000000
.04486549	.95513451	1.00000000

ASSIGNED 8 NUMBER OF THREE LEVELS 3 MIX= 4.25

PROBABILITY TABLE

EE	FIVE	MARGINAL	DIFF
.00520119	.00891337	.01411456	.00010157
.00841108	.01105326	.01946434	-.00121852
.01275750	.02106206	.03381956	-.00008166
.01134122	.02156166	.03290288	.00109186
.00356939	.00458366	.00815305	-.00056441
.00072435	.00141210	.00213644	.00008495
.00558750	.01037938	.01596688	.00044042
.00280438	.00460238	.00740676	-.00002834
.00620798	.00972402	.01593200	-.00025513
.01115725	.01321723	.02437448	-.00221028
.00615375	.01161438	.01776813	.00155688
.00656329	.01403347	.02059676	.00127224
.00620798	.00972402	.01593200	-.00025513
.00427947	.00643124	.01071072	-.00028847
.00242250	.00493875	.00736125	.00037075
.00656329	.01403347	.02059676	.00127224
.00272778	.00375447	.00648225	-.00032489
.00286936	.00334002	.00620938	-.00059329
.00853125	.01103463	.01956588	-.00131028
.00478149	.00621130	.01099279	-.00072201
.00020813	.00090171	.00110984	.00022787
.00051474	.00081558	.00133032	-.00001767
.00015000	.00218522	.00233522	.00079530
.00005087	.00180507	.00185594	.00070652
.37500000	.52500000	1.00000000	.00061629

CONDITIONAL PROBABILITY TABLE

THREE	FIVE	UNITY
.36849834	.63150166	1.00000000
.43212746	.56787254	1.00000000
.37722250	.62277750	1.00000000
.34468781	.65531219	1.00000000
.43779769	.56220231	1.00000000
.33904234	.66095766	1.00000000
.34994324	.65005676	1.00000000
.37862488	.62137512	1.00000000
.38965474	.61034526	1.00000000
.45774312	.54225688	1.00000000
.34633649	.65366351	1.00000000
.31865628	.68134372	1.00000000
.38965474	.61034526	1.00000000
.39955063	.60044937	1.00000000
.32908813	.67091187	1.00000000
.31865628	.68134372	1.00000000
.42080700	.57919300	1.00000000
.46210119	.53789881	1.00000000
.43602701	.56397299	1.00000000
.43496569	.56503431	1.00000000
.18753522	.81246478	1.00000000
.38692971	.61307029	1.00000000
.06423381	.93576619	1.00000000
.02741122	.97258878	1.00000000

PERSONNEL ASSIGNED 8 NUMBER OF THREE LEVELS 2 MIX= 4.5

JOINT PROBABILITY TABLE

THREE	FIVE	MARGINAL	DIFF
.00346746	.01069604	.01416350	.00085263
.00560738	.01326392	.01887130	-.00062548
.00850500	.02527448	.03377948	-.00004157
.00756081	.02587399	.03343480	.00055994
.00237959	.00550040	.00787999	-.00029135
.00048290	.00169452	.00217742	.00004397
.00372500	.01245525	.01618025	.00022705
.00185959	.00552285	.00739244	-.00001422
.00413865	.01166882	.01580747	-.00013061
.00743817	.01586068	.02329884	-.00113464
.00410250	.01393725	.01803975	.00028525
.00437552	.01684016	.02121569	.00065331
.00413865	.01166882	.01580747	-.00013061
.00285298	.00771749	.01057047	-.00014823
.00161500	.00592650	.00754150	.00019050
.00437552	.01684016	.02121569	.00065331
.00181852	.00450537	.00632388	-.00016652
.00191291	.00400802	.00592093	-.00030484
.00568750	.01324155	.01892905	-.00067345
.00318766	.00745355	.01064122	-.00037044
.00013876	.00108205	.00122080	.00011691
.00034316	.00097870	.00132186	-.00000921
.00010000	.00262226	.00272226	.00040826
.00003392	.00216608	.00220000	.00036246
.25000000	.75000000	1.00000000	.00031645

CONDITIONAL PROBABILITY TABLE

THREE	FIVE	UNITY
.24481664	.75518336	1.00000000
.29713818	.70286182	1.00000000
.25178011	.74821989	1.00000000
.22613604	.77386396	1.00000000
.30197904	.69802096	1.00000000
.22177515	.77822485	1.00000000
.23021894	.76978106	1.00000000
.25290552	.74709448	1.00000000
.26181615	.73818385	1.00000000
.31925050	.68074950	1.00000000
.22741446	.77258554	1.00000000
.20624001	.79375999	1.00000000
.26181615	.73818385	1.00000000
.26990108	.73009892	1.00000000
.21414838	.78585162	1.00000000
.20624001	.79375999	1.00000000
.28756329	.71243671	1.00000000
.32307560	.67692440	1.00000000
.30046410	.69953590	1.00000000
.29955749	.70044251	1.00000000
.11365965	.88634035	1.00000000
.25960488	.74039512	1.00000000
.03673415	.96326585	1.00000000
.01541627	.98458373	1.00000000

PERSONNEL ASSIGNED 8 NUMBER OF THREE LEVELS 1 MIX= 4.75

JOINT PROBABILITY TABLE

THREE	FIVE	MARGINAL	DIFF
.00173373	.01247871	.01421244	.00000369
.00280369	.01547457	.01827826	-.00003244
.00425250	.02948689	.03373939	-.00000149
.00378041	.03018632	.03396673	.00002801
.00118980	.00641713	.00760592	-.00001828
.00024145	.00197694	.00221839	.00000300
.00186250	.01453113	.01639363	.00001368
.00093479	.00644333	.00737812	.00000010
.00206933	.01361363	.01568295	-.00000609
.00371908	.01850412	.02222321	-.00005900
.00205125	.01626013	.01831138	.00001363
.00218776	.01964686	.02183462	.00003438
.00206933	.01361363	.01568295	-.00000609
.00142549	.00900374	.01043023	-.00000799
.00080750	.00691425	.00772175	.00001025
.00218776	.01964686	.02183462	.00003438
.00090926	.00525626	.00616552	-.00000816
.00095645	.00467603	.00563248	-.00001639
.00284375	.01544849	.01829223	-.00003663
.00159383	.00869582	.01028965	-.00001887
.00006938	.00126239	.00133177	.00000594
.00017156	.00114181	.00131340	-.00000074
.00005000	.00305931	.00310931	.00002121
.00001696	.00252709	.00254405	.00001841
.12500000	.87500000	1.00000000	.00001662

CONDITIONAL PROBABILITY TABLE

THREE	FIVE	UNITY
.12198679	.87801321	1.00000000
.15338942	.84661058	1.00000000
.12603963	.87396037	1.00000000
.11129736	.88870264	1.00000000
.15640953	.84359047	1.00000000
.10883959	.89116041	1.00000000
.11361124	.88638876	1.00000000
.12669818	.87330182	1.00000000
.13194748	.86805252	1.00000000
.16735136	.83264864	1.00000000
.11202053	.88797947	1.00000000
.10019693	.89980307	1.00000000
.13194748	.86805252	1.00000000
.13676506	.85323494	1.00000000
.10457474	.89542526	1.00000000
.10019693	.89980307	1.00000000
.14747473	.85252527	1.00000000
.16981047	.83016953	1.00000000
.15546223	.84453777	1.00000000
.15489626	.84510374	1.00000000
.05209475	.94790525	1.00000000
.13063895	.86936105	1.00000000
.01608076	.98391924	1.00000000
.00666569	.99333431	1.00000000

PERSONNEL ASSIGNED 13 NUMBER OF THREE LEVELS 9 MIX= 3.2

JOINT PROBABILITY TABLE THREE	FIVE	MARGINAL	DIFF	CONDITIONAL PROBABILITY TABLE THREE	FIVE	UNITY
.01248286	.00142614	.01390900	.00030713	.89746646	.10253354	1.00000000
.02018558	.00176852	.02195510	-.00370926	.91944824	.08055176	1.00000000
.03061808	.00336993	.03398793	-.00025083	.90084921	.09915079	1.00000000
.02721893	.00344987	.03066880	.00332595	.88751220	.11248780	1.00000000
.00856653	.00073339	.00929991	-.00171127	.92114054	.07885946	1.00000000
.00173843	.00022594	.00196436	.00025703	.88498269	.11501731	1.00000000
.01341000	.00166070	.01507070	.00133660	.88980605	.11019395	1.00000000
.00673052	.00073638	.00746690	-.00008868	.90138074	.09861926	1.00000000
.01489915	.00155584	.01645499	-.00077813	.90544856	.09455144	1.00000000
.02677740	.00211476	.02889216	-.00672796	.92680517	.07319483	1.00000000
.01476900	.00185830	.01662730	.00169770	.88823802	.11176198	1.00000000
.01575189	.00224536	.01799724	.00387176	.87523892	.12476108	1.00000000
.01489915	.00155584	.01645499	-.00077813	.90544856	.09455144	1.00000000
.01027074	.00102900	.01129974	-.00087749	.90893602	.09106398	1.00000000
.00581400	.00079020	.00660420	.00112780	.88034887	.11965113	1.00000000
.01575189	.00224536	.01799724	.00387176	.87523892	.12476108	1.00000000
.00654666	.00060072	.00714738	-.00099002	.91595299	.08404701	1.00000000
.00688647	.00053440	.00742087	-.00180473	.92798650	.07201350	1.00000000
.02047500	.00176554	.02224054	-.00393494	.92061614	.07938386	1.00000000
.01147557	.00099381	.01246938	-.00219859	.92030006	.07969994	1.00000000
.00049952	.00014427	.00064379	.00069391	.77590227	.22409773	1.00000000
.00123538	.00013049	.00136587	-.00005322	.90446178	.09553822	1.00000000
.00036000	.00034964	.00070964	.00242089	.50730305	.49269695	1.00000000
.00012210	.00028881	.00041091	.00215155	.29713910	.70286090	1.00000000
.90000000	.10000000	1.00000000	.00187561			

PERSONNEL ASSIGNED TO NUMBER OF THREE LEVELS 8 MI X= 3.4

JOINT PROBABILITY TABLE

THREE	FIVE	MARGINAL	DIFF
.01109588	.00285228	.01394815	.00026798
.01794363	.00353784	.02148067	-.00323485
.02721600	.00673986	.03395586	-.00021796
.02419460	.00689973	.03109434	.00290041
.00761469	.00146677	.00908146	-.00149282
.00154527	.00045187	.00199714	.00022425
.01192000	.00332140	.01524140	.00116590
.00598268	.00147276	.00745545	-.00007722
.01324369	.00311169	.01635537	-.00067851
.02380214	.00422951	.02803165	-.00586745
.01312800	.00371660	.01684460	.00148040
.01400168	.00449071	.01849239	.00337661
.01324369	.00311169	.01635537	-.00067851
.00912954	.00205800	.01118754	-.00076530
.00516800	.00158040	.00674840	.00098360
.01400168	.00449071	.01849239	.00337661
.00581925	.00120143	.00702069	-.00086332
.00612131	.00106881	.00719011	-.00157402
.01820000	.00353108	.02173108	-.00347548
.01020050	.00198762	.01218812	-.00191734
.00044402	.00028855	.00073256	.00060514
.00109812	.00026099	.00135910	-.00004645
.00032000	.00069927	.00101927	.00211125
.00010853	.00057762	.00068615	.00187631
.80000000	.20000000	1.00000000	.00163574

CONDITIONAL PROBABILITY TABLE

THREE	FIVE	UNITY
.79550858	.20449142	1.00000000
.83533828	.16466172	1.00000000
.80151114	.19848886	1.00000000
.77810330	.22189670	1.00000000
.83848723	.16151277	1.00000000
.77374072	.22625928	1.00000000
.78208039	.21791961	1.00000000
.80245842	.19754158	1.00000000
.80974533	.19025467	1.00000000
.84911649	.15088351	1.00000000
.77935956	.22064044	1.00000000
.75715895	.24284105	1.00000000
.80974533	.19025467	1.00000000
.81604557	.18395443	1.00000000
.76581116	.23418884	1.00000000
.75715895	.24284105	1.00000000
.82887265	.17112735	1.00000000
.85135059	.14864941	1.00000000
.83751015	.16248985	1.00000000
.83692179	.16307821	1.00000000
.60611580	.39388420	1.00000000
.80737157	.19202843	1.00000000
.31395018	.68604982	1.00000000
.15817251	.84182749	1.00000000

PERSONNEL ASSIGNED 10 NUMBER OF THREE LEVELS 7 MIX= 3.6

JOINT PROBABILITY TABLE

THREE	FIVE	MARGINAL	DIFF
.00970889	.00427842	.01398731	.00022883
.01570067	.00530557	.02100624	-.00276042
.02381400	.01010979	.03392379	-.00018589
.02117028	.01034960	.03151987	.00247467
.00666285	.00220016	.00886301	-.00127437
.00135211	.00067781	.00202992	.00019147
.01043000	.00498210	.01541210	.00099520
.00523485	.00220914	.00744399	-.00006577
.01158823	.00466753	.01625575	-.00057089
.02082687	.00634427	.02717114	-.00500694
.01148700	.00557490	.01706190	.00126310
.01225147	.00673607	.01898753	.00288146
.01158823	.00466753	.01625575	-.00057089
.00798835	.00308700	.01107535	-.00065310
.00452200	.00237060	.00689260	.00083940
.01225147	.00673607	.01898753	.00288146
.00509185	.00180215	.00689399	-.00073653
.00535614	.00160321	.00695935	-.00134326
.01592500	.00529662	.02122162	-.00296602
.00892544	.00298143	.01190687	-.00163608
.00038852	.00043282	.00082134	.00051637
.00096085	.00039148	.00135233	-.00003968
.00028000	.00104891	.00132891	.00180162
.00009496	.00085643	.00096140	.00160106
.70000000	.30000000	1.00000000	.00139587

CONDITIONAL PROBABILITY TABLE

THREE	FIVE	UNITY
.69412151	.30587849	1.00000000
.74742903	.25257097	1.00000000
.70198524	.29801476	1.00000000
.67164858	.32835142	1.00000000
.75175954	.24824046	1.00000000
.66609120	.33390880	1.00000000
.67674100	.32325900	1.00000000
.70323165	.29676835	1.00000000
.71286913	.28713087	1.00000000
.76650701	.23349299	1.00000000
.67325444	.32674556	1.00000000
.64523743	.35476257	1.00000000
.71286913	.28713087	1.00000000
.72127315	.27672685	1.00000000
.65606593	.34393407	1.00000000
.64523743	.35476257	1.00000000
.73859176	.26140824	1.00000000
.76963244	.23036756	1.00000000
.75041396	.24958604	1.00000000
.74960452	.25039548	1.00000000
.47303060	.52696940	1.00000000
.71051507	.28948493	1.00000000
.21069979	.78930021	1.00000000
.09877723	.90122277	1.00000000

PERSONNEL ASSIGNED 11 NUMBER OF THREE LEVELS 6 MIX= 3.8

JOINT PROBABILITY TABLE

THREE	FIVE	MARGINAL	DIFF
.00832191	.00570456	.01402646	.00018967
.01345772	.00707409	.02053181	-.00228599
.02041200	.01347972	.03389172	-.00015382
.01814595	.01379946	.03194541	.00204933
.00571102	.00293354	.00854456	-.00105592
.00115895	.00090374	.00206270	.00015869
.00894000	.00664280	.01558280	.00082450
.00448701	.00294552	.00743253	-.00005431
.00993276	.00622337	.01515614	-.00047927
.01785160	.00845903	.02631063	-.00414643
.00984600	.00743320	.01727920	.00104580
.01050126	.00898142	.01948268	.00238632
.00993276	.00622337	.01615614	-.00047927
.00684716	.00411600	.01096315	-.00054091
.00387500	.00316080	.00703680	.00069520
.01050126	.00898142	.01948268	.00238632
.00436444	.00240286	.00676730	-.00060994
.00459098	.00213751	.00672859	-.00111250
.01365000	.00706216	.02071216	-.00245656
.00765038	.00397523	.01162561	-.00135483
.00033301	.00057709	.00091011	.00042760
.00082359	.00052197	.00134556	-.00043291
.00024000	.00139854	.00163854	.00149198
.00008140	.00115524	.00123664	.00132582
.60000000	.40000000	1.00000000	.00115600

CONDITIONAL PROBABILITY TABLE

THREE	FIVE	UNITY
.59330048	.40669952	1.00000000
.65545712	.34454288	1.00000000
.60227100	.39772900	1.00000000
.56803000	.43197000	1.00000000
.66054859	.33935141	1.00000000
.56186289	.43813711	1.00000000
.57370947	.42629053	1.00000000
.60359900	.39630100	1.00000000
.61479827	.38520173	1.00000000
.67849392	.32150608	1.00000000
.56981805	.43018195	1.00000000
.53900480	.46099520	1.00000000
.61479827	.38520173	1.00000000
.62456098	.37543902	1.00000000
.55081855	.44918145	1.00000000
.53900480	.46099520	1.00000000
.64493056	.35506944	1.00000000
.68230916	.31769084	1.00000000
.65903315	.34096685	1.00000000
.65806239	.34193761	1.00000000
.36590730	.63409270	1.00000000
.61207770	.38792230	1.00000000
.14647186	.85352814	1.00000000
.06582168	.93417832	1.00000000

PERSONNEL ASSIGNED 1? NUMBER OF THREE LEVELS 5 MIX= 4.

JOINT PROBABILITY TABLE

THREE	FIVE	MARGINAL	DIFF
.00693492	.00713669	.01406562	.00015052
.01121477	.00884251	.02005738	-.00181156
.01701000	.01684965	.03385965	-.00012175
.01512163	.01724933	.03237095	.00162379
.00475918	.00366693	.00842611	-.00083747
.00696579	.00112958	.00809547	.00012592
.00745000	.00830350	.01575350	.00065380
.00373916	.00368190	.00742106	-.00004286
.00827730	.00777921	.01605652	-.00037966
.01487533	.01057378	.02545012	-.00329592
.00820500	.00929150	.01749650	.00082850
.00875105	.01122678	.01997782	.00189117
.00827730	.00777921	.01605652	-.00037966
.00572597	.00514499	.01085096	-.00042872
.00323000	.00395110	.00718100	.00055100
.00675105	.01122678	.01797782	.00189117
.00363703	.00300359	.00664061	-.00048325
.00382582	.00267202	.00649783	-.00088174
.01137500	.00882770	.02020270	-.00194710
.00637532	.00496904	.01134436	-.00107357
.00027751	.00072136	.00099888	.00033883
.00068532	.00065247	.00133879	-.00002614
.0002[illegible]	.00174618	.00194818	.00118235
.00006783	.00144445	.00151189	.00105657
.50091[illegible]	.50[illegible]	1.00000000	.00091613

CONDITIONAL PROBABILITY TABLE

THREE	FIVE	UNITY
.49304476	.50695924	1.[illegible]
.55913426	.44186574	1.[illegible]
.50236786	.49763214	1.[illegible]
.46713569	.53286431	1.[illegible]
.56481346	.43518654	1.[illegible]
.46089524	.53910476	1.[illegible]
.47291078	.52708922	1.[illegible]
.50385907	.49614093	1.[illegible]
.51551050	.48448950	1.[illegible]
.58452909	.41547091	1.[illegible]
.46885093	.53114907	1.[illegible]
.43803808	.56196192	1.[illegible]
.51551050	.48448950	1.[illegible]
.52584888	.47415112	1.[illegible]
.44979808	.55020192	1.[illegible]
.43803808	.56196192	1.[illegible]
.54769558	.45230442	1.[illegible]
.58878359	.41121641	1.[illegible]
.56304355	.43695645	1.[illegible]
.56198114	.43801886	1.[illegible]
.27782416	.72217584	1.[illegible]
.51264457	.48735543	1.[illegible]
.10266118	.89733882	1.[illegible]
.04486549	.95513451	1.[illegible]

PERSONNEL ASSIGNED 1' NUMBER OF THREE LEVELS 4 MIX= 4.2

JOINT PROBABILITY TABLE

THREE	FIVE	MARGINAL	DIFF
.00554796	.00855683	.01410477	.00011136
.00897181	.01061113	.01958295	-.00133713
.01360800	.02021958	.03382758	-.00408968
.01209730	.02069919	.03279649	.00119825
.00386735	.00440032	.00826766	-.00061902
.00077263	.00135562	.00212825	.00009314
.00596366	.00996420	.01592420	.00048310
.00299134	.00441828	.00740962	-.00063140
.00662184	.00933506	.01595690	-.00128004
.01195107	.01268854	.02458961	-.00242541
.00656411	.01114980	.01771386	.00061120
.00700084	.01347213	.02047297	.00139603
.00662184	.00933506	.01595690	-.00128004
.00456477	.00617399	.01073877	-.00031652
.00258496	.00474126	.00732520	.00040680
.00700084	.01347213	.02047297	.00139603
.00290963	.00360423	.00651392	-.00035656
.00306065	.00320642	.00626707	-.00065098
.00910000	.01059324	.01969324	-.00143764
.00510025	.00596285	.01106310	-.00079232
.00022201	.00086564	.00108765	.00025006
.00054306	.00078296	.00132602	-.00011937
.00016000	.00209781	.00225781	.00187271
.00005427	.00173287	.00178713	.00077533
[illegible]	[illegible]	1.00000000	.00167625

CONDITIONAL PROBABILITY TABLE

THREE	FIVE	UNITY
.39333768	.60666232	1.00000000
.45814422	.54185578	1.00000000
.40227530	.59772470	1.00000000
.36885963	.63114037	1.00000000
.46387696	.53612304	1.00000000
.36303759	.63696241	1.00000000
.37427312	.62572688	1.00000000
.40371044	.59628956	1.00000000
.41498304	.58501696	1.00000000
.48358769	.51641231	1.00000000
.37055855	.62944145	1.00000000
.34195518	.65804482	1.00000000
.41498304	.58501696	1.00000000
.42507418	.57492582	1.00000000
.35275487	.64724513	1.00000000
.34195518	.65804482	1.00000000
.44667830	.55332170	1.00000000
.48837659	.51162341	1.00000000
.46208750	.53791250	1.00000000
.46101460	.53898540	1.00000000
.20411919	.79588081	1.00000000
.41221649	.58778351	1.00000000
.07086513	.92913487	1.00000000
.03036443	.96963557	1.00000000

PERSONNEL ASSIGNED 1' NUMBER OF THREE LEVELS 3 MIX= 4.4

JOINT PROBABILITY TABLE

THREE	FIVE	MARGINAL	DIFF
.00416095	.00998297	.01414392	.00007221
.00672886	.01237965	.01910852	-.00186270
.01020600	.02358951	.03379551	-.00065761
.00907298	.02414916	.03322203	.00077271
.00285551	.00513370	.00798921	-.00040057
.00057948	.00158155	.00216103	.00006036
.00447000	.01162490	.01609490	.00031240
.00224351	.00515466	.00739817	-.00001995
.00496538	.01089190	.01585726	-.00018042
.00892580	.01480330	.02372910	-.00156490
.00492300	.01300810	.01793110	.00039390
.00525063	.01571749	.02096812	.00090088
.00496638	.01089090	.01585728	-.00118042
.00342358	.00720299	.01062657	-.00020433
.00193800	.00553140	.00746940	.00126260
.00525063	.01571749	.02096812	.00090088
.00218222	.00420501	.00638723	-.00022987
.00229549	.00374082	.00603631	-.00042022
.00682500	.01235878	.01918378	-.00092818
.00382519	.00695666	.01078185	-.00051106
.00016651	.00100991	.00117642	.00016129
.00041179	.00091345	.00132525	-.00001259
.00012000	.00244745	.00256745	.00156308
.00004070	.00202168	.00206237	.00050008
.30000000	.70000000	1.00000000	.00043638

CONDITIONAL PROBABILITY TABLE

THREE	FIVE	UNITY
.29418661	.70581339	1.00000000
.35213936	.64786064	1.00000000
.30199278	.69800722	1.00000000
.27310119	.72689881	1.00000000
.35742061	.64257939	1.00000000
.26814844	.73185156	1.00000000
.27772773	.72227227	1.00000000
.30325166	.69674834	1.00000000
.31319252	.68680748	1.00000000
.37615423	.62384577	1.00000000
.27455192	.72544808	1.00000000
.25041613	.74958387	1.00000000
.31319252	.68680748	1.00000000
.32217155	.67782845	1.00000000
.25945859	.74054141	1.00000000
.25041613	.74958387	1.00000000
.34165364	.65834636	1.00000000
.38028027	.61971973	1.00000000
.35576934	.64423066	1.00000000
.35478044	.64521956	1.00000000
.14153752	.85846248	1.00000000
.31072998	.68927002	1.00000000
.04673907	.95326093	1.00000000
.01973400	.98026600	1.00000000

PERSONNEL ASSIGNED 11 NUMBER OF THREE LEVELS 2 MIX= 4.5

JOINT PROBABILITY TABLE

THREE	FIVE	MARGINAL	DIFF
.00277397	.01140911	.01418308	.00003305
.00448591	.01414818	.01853408	-.00038827
.00680400	.02695944	.03376344	-.00002554
.00601865	.02759892	.03361757	.00034717
.00190367	.00586709	.00777076	-.00018212
.00038532	.00180749	.00219380	.00002759
.00298000	.01328560	.01626560	.00014170
.00149567	.00589194	.00738671	-.00000849
.00331092	.01244674	.01575767	-.00009080
.00595553	.01691865	.02286853	-.00070439
.00328200	.01486640	.01814840	.00017660
.00350042	.01796284	.02146326	.00040574
.00331092	.01244674	.01575767	-.00009080
.00228239	.00823199	.01051438	-.00009213
.00129200	.00632160	.00761360	.00011840
.00350042	.01796284	.02146326	.00040574
.00145081	.00480573	.00626054	-.00010318
.00153033	.00427523	.00580555	-.00018946
.00455000	.01412432	.01957432	-.00041872
.00255[illegible]13	.00795[illegible]47	.01050[illegible]59	-.00022981
.00011101	.00115418	.00126519	.00007252
.00027453	.00104395	.00131847	-.00000582
.00008[illegible]01	.00279709	.00287708	.00025344
.00002713	.00231049	.00233762	.00022484
.20000000	.80000000	1.00000000	.00019651

CONDITIONAL PROBABILITY TABLE

THREE	FIVE	UNITY
.19558298	.80441712	1.[illegible]
.24073664	.75926336	1.[illegible]
.20151975	.79848025	1.[illegible]
.17976486	.82023514	1.[illegible]
.24497898	.75502117	1.[illegible]
.17609472	.82390528	1.[illegible]
.18320873	.81679127	1.[illegible]
.20248130	.79751870	1.[illegible]
.21011498	.78988502	1.[illegible]
.26020556	.73979444	1.[illegible]
.18084239	.81915761	1.[illegible]
.16308867	.83691113	1.[illegible]
.21011498	.78988502	1.[illegible]
.21707286	.78292714	1.[illegible]
.16969633	.83030367	1.[illegible]
.16308887	.83691113	1.[illegible]
.23237833	.76762167	1.[illegible]
.26359715	.73640285	1.[illegible]
.24355010	.75644990	1.[illegible]
.24285540	.75714460	1.[illegible]
.08773784	.91226224	1.[illegible]
.23821721	.76178279	1.[illegible]
.02780597	.97219403	1.[illegible]
.01150694	.98839316	1.[illegible]

PERSONNEL ASSIGNED 10 NUMBER OF THREE LEVELS 1 MIX= 4.3

JOINT PROBABILITY TABLE

THREE	FIVE	MARGINAL	DIFF
.00138698	.01283525	.01422223	-.00001610
.00224295	.01591670	.01815965	.00008617
.00340200	.03032937	.03373137	.00000653
.00302433	.03104879	.03407311	-.00007837
.00095184	.00660048	.00755231	.00003633
.00019316	.00203342	.00222658	-.00000519
.00149000	.01494630	.01643630	-.00002900
.00074784	.00662742	.00737526	.00000296
.00165546	.01400259	.01565805	.00001882
.00297527	.01903281	.02200808	.00015612
.00164100	.01672470	.01836570	-.00004070
.00175021	.02020820	.02195841	-.00008941
.00165546	.01400259	.01565805	.00001882
.00114119	.00926099	.01040218	.00002096
.00064600	.00711100	.00775780	-.00002580
.00175021	.02020820	.02195841	-.00008941
.00072741	.00540644	.00613385	.00002351
.00076516	.00480963	.00557479	.00004130
.00227500	.01588986	.01816486	.00009074
.00127500	.00894429	.01021934	.00005144
.00005550	.00129846	.00135396	-.00001625
.00013726	.00117444	.00131170	.00000095
.00004000	.00314672	.00318672	-.00005619
.00001357	.00259930	.00261286	-.00005041
.10000000	.90000000	1.00000000	.00004336

CONDITIONAL PROBABILITY TABLE

THREE	FIVE	UNITY
.09752226	.90247774	1.00000000
.12351301	.87648699	1.00000000
.10085567	.89914433	1.00000000
.08875989	.91124011	1.00000000
.12603245	.87396755	1.00000000
.08675123	.91324877	1.00000000
.09065301	.90934699	1.00000000
.10139790	.89860210	1.00000000
.10572588	.89427412	1.00000000
.13518977	.86481023	1.00000000
.08935135	.91064865	1.00000000
.07970567	.92029433	1.00000000
.10572588	.89427412	1.00000000
.10970706	.89029294	1.00000000
.08327103	.91672897	1.00000000
.07970567	.92029433	1.00000000
.11858899	.88141101	1.00000000
.13725419	.86274581	1.00000000
.12524181	.87475819	1.00000000
.12476961	.87523039	1.00000000
.14099269	.85900731	1.00000000
.10461604	.89538396	1.00000000
.01255211	.98744789	1.00000000
.00519212	.99480788	1.00000000

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